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Volume 24 JUNE, 1954 Number 2

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal*, should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

Among papers to appear in forthcoming issues of the *Journal* are the following:

A technique for separating clay minerals from limestones. By R. M. Lloyd.

Submarine geology of the San Pedro shelf. By D. G. Moore.

Paleontology and paleoecology of San Pedro shelf and vicinity. By R. W. Crouch.

A modified Kullenberg piston corer. By George R. Emery.

The clay minerals of the Neuse River sediments. By Charles Q. Brown and Roy L. Ingram.

Surface textures of sand grains from the Victoria Falls area. By Geoffrey Bond.

Note on graphite in the Cretaceous of southern Illinois. By Raymond S. Shrode.

Nomenclature based on sand-silt-clay ratios. By Francis P. Shepard.

Sorting nomenclatural assortment. By Richard L. Threet.

The petrology of the Vincentown formation. By Seymour Oscar Schlanger.

"ERRATA

A mis-statement occurs in the writer's recent paper on Latin squares (This Journal, vol. 23, pp. 280–283, 1953). The Latin square is described as a randomized block model, whereas it is more properly a 'fractional factorial design.' On p. 283, col. 1, line 11, the value 4.26 mm should be 5.74 mm.

W. C. KRUMBEIN"

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 24, NO. 2, PP. 71–75
PLATE I, TEXT FIGS. 1–3, JUNE, 1954

CEMENTED SANDSTONE SLABS OF THE CHANDELEUR ISLANDS, LOUISIANA

JAMES P. MORGAN AND ROBERT C. TREADWELL
School of Geology, Louisiana State University, Baton Rouge 3, Louisiana

ABSTRACT

Cemented slabs of fine-grained sandstone litter the beach along the central Chandeleur Islands, St. Bernard Parish, Louisiana. Such slabs are found elsewhere on the coastal islands of Louisiana. The factors responsible for secondary cementation of beach sands are: (1) the long, narrow, barrier nature of the Chandeleurs which makes possible a difference in height of sea level on opposite sides of the islands, (2) the presence of calcium carbonate in the form of finely pulverized shell in the beach sands and (3) the availability of organic acids from decaying mangrove vegetation. Cemented sandstone slabs originate at the plugged mouths of tidal channels.

INTRODUCTION

This paper is a result of observations made during field work in connection with Office of Naval Research Contract N7 onr 35608, conducted by the School of Geology, Louisiana State University.

The area studied consists of the central part of the Chandeleur Islands of Louisiana, a relatively inaccessible group of islands located in the Gulf of Mexico about twenty-five miles south of Biloxi, Mississippi.

While conducting field work it was noted that in many places the beach of these barrier islands is littered with well-indurated sandstone slabs of very recent origin. This paper concerns the mode of development of the sandstone slabs.

GEOLOGICAL SETTING

The Chandeleur Islands are a long, arcuate, discontinuous series of islands located some twenty miles east of the mainland of St. Bernard Parish, Louisiana. The islands cover an area nearly forty miles long but seldom exceed one mile in width.

St. Bernard Parish comprises part of a low-lying former sub-delta of the Mississippi River (Russell, 1936). It was developed when the Mississippi River was discharging eastward from New Orleans some 350 (?)–800 (?) years ago. The river has since abandoned its St. Bernard system of distributaries in favor of its present course to the Lower Delta. Deprived of continuing sedimentation, the entire sub-delta has been gradually subsiding due to compaction of sediments and downwarping of the Gulf Coast Geosyncline.

Wave action is rapidly enlarging lakes and bays at the expense of marsh and natural levees. In the Chandeleur Sound area the original land has subsided below water level and wave action has developed fairly constant water depths ranging from eight to fifteen feet.

The Chandeleurs are barrier islands composed of fine sand and shell thrown up by wave action as the delta front retreats under wave attack. Water depths in the Gulf of Mexico immediately outside the Chandeleur Islands average twenty to fifty feet.

The islands are constantly being reworked by wave action. Storms erode the Gulf side of the islands and throw sediment across to the westward side of the barrier. Thus, the entire arc of islands is retreating in a generally westward direction.

PHYSICAL CHARACTERISTICS OF THE CHANDELEUR ISLANDS

The sediment composing the central part of the islands is extremely well-sorted and consists predominantly of fine sand with a small amount of very fine

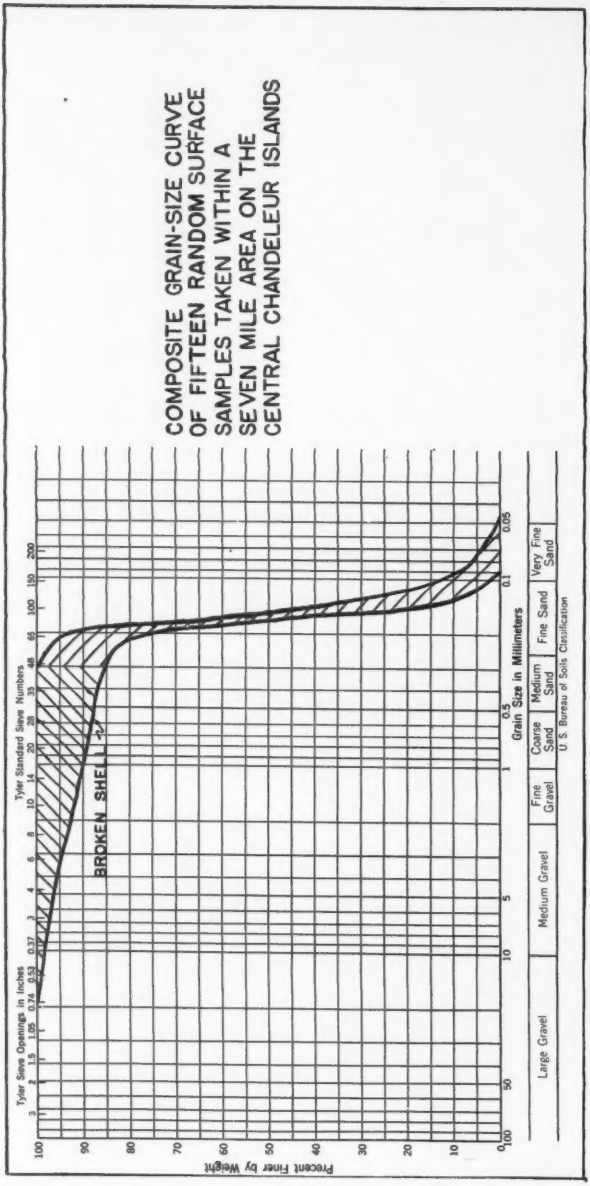
COMPOSITE GRAIN-SIZE CURVE
OF FIFTEEN RANDOM SURFACE
SAMPLES TAKEN WITHIN A
SEVEN MILE AREA ON THE
CENTRAL CHANDELEUR ISLANDS
BROKEN SHELL
Tyler Sieve Openings in Inches
Tyler Standard Sieve Numbers
Percent Finer by Weight
Grain Size in Millimeters
Large Gravel
Medium Gravel
Fine Gravel
Coarse Sand
Medium Sand
Fine Sand
Very Fine Sand
U.S. Bureau of Soils Classification

FIG. 1

sand and a variable quantity of coarser shell material. Figure 1 is a composite grain-size curve of fifteen random samples taken in the central part of the Chandeleur Arc.

The average elevation of the beach ridge fronting the Gulf of Mexico is about five feet above mean Gulf level. The beach averages some 450 feet wide and is flanked on the westward side by a zone of low, black mangrove march (*Avicennia nitida*). Mangrove marsh in the central Chandeleur Islands averages about one-half mile in width and has an elevation of less than one foot above mean Gulf level.

A random cross section of the central Chandeleurs is reproduced as figure 2. It shows the typical, relatively narrow, high, sand beach backed by a broad, low area of mangrove marsh. As the beach ridge is driven west by the combined action of wind and water, the mangrove marsh is buried and killed. Within a comparatively short time the beach passes across and the old decayed mangrove stumps are exhumed and exposed on the Gulf side of the island.

Numerous tidal drainage channels have established themselves across the mangrove marsh. These channels terminate abruptly on the Gulf side at the retreating beach ridge (fig. 3).

The channels through the mangrove are kept open through tidal changes. Normal lunar tides in this area seldom exceed eighteen inches but wind tides often amount to several feet. Due to the length and the isolated position of the Chandeleur Arc the water level in Chandeleur Sound often is two or three feet higher than the Gulf of Mexico and vice versa.

DEVELOPMENT OF CEMENTED SANDSTONE SLABS

The mangrove marsh on the landward side of the island arc is slowly buried by sediment washed and blown across the beach ridge. The buried mangrove decays and makes available organic acids to the water which percolates through the

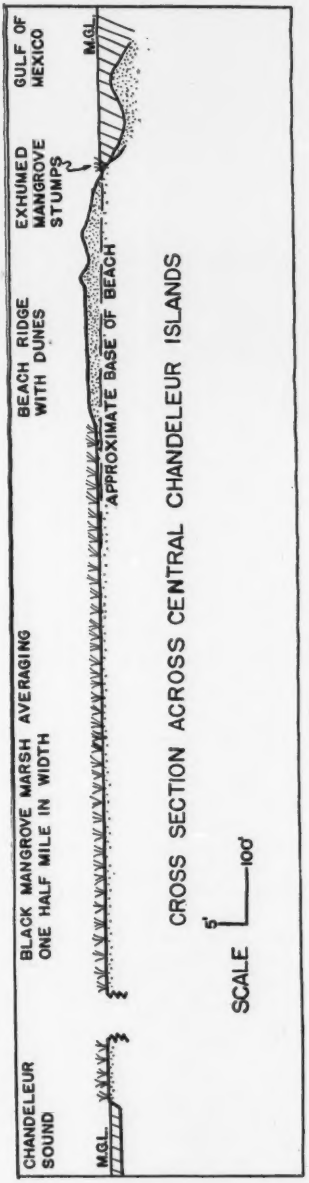

FIG. 2

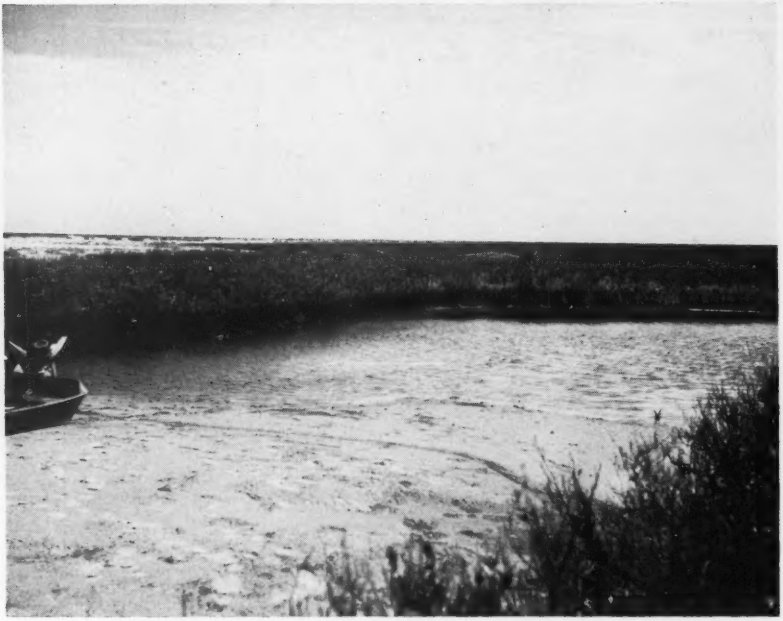

FIG. 3.—Plugged mouth of Monkey Bayou, Central Chandeleur Islands. Tidal channel through mangrove marsh is plugged in the foreground by the retreating sand beach.

permeable and porous sediments of the islands. The acidified waters react with the 10 to 15 per cent of finely pulverized shell present in the average sediments. Part of the shell goes into solution and calcium carbonate is concentrated in the waters of the tidal drainage channels.

When the prevailing winds come from the northwest, west or southwest, waters of the Chandeleur Sound are forced across the mangrove marsh toward the elevated beach ridge. A hydraulic head is established between the high waters of the Sound and the lower waters of the Gulf. Water percolates everywhere through the beach sands to the Gulf but the principal means of egress is through the sand beach plugging the mouths of the tidal channels. Evaporation of water percolating through the barrier beach leaves a residual deposit of calcium carbonate in the interstitial spaces of the surface sediments thereby forming cemented sandstone slabs. Only thin cemented layers 1/16 to $\frac{1}{8}$ inch in thickness have been present at mouths of plugged tidal channels during times of field examination but the beach in the immediate areas is littered with slabs ranging in thickness from $\frac{1}{4}$ inch to 2 inches. The average thickness is about $\frac{1}{2}$ inch. The slabs apparently were formed at an earlier time and broken up by storm waves. Most of them have been exposed for a sufficient period of time to show the effects of wind abrasion.

CHARACTERISTICS OF SANDSTONE SLABS

Most slabs are composed of moderately- to well-cemented fine sands. Iron stains indicate a variable quantity of iron as a supplemental cementing agent

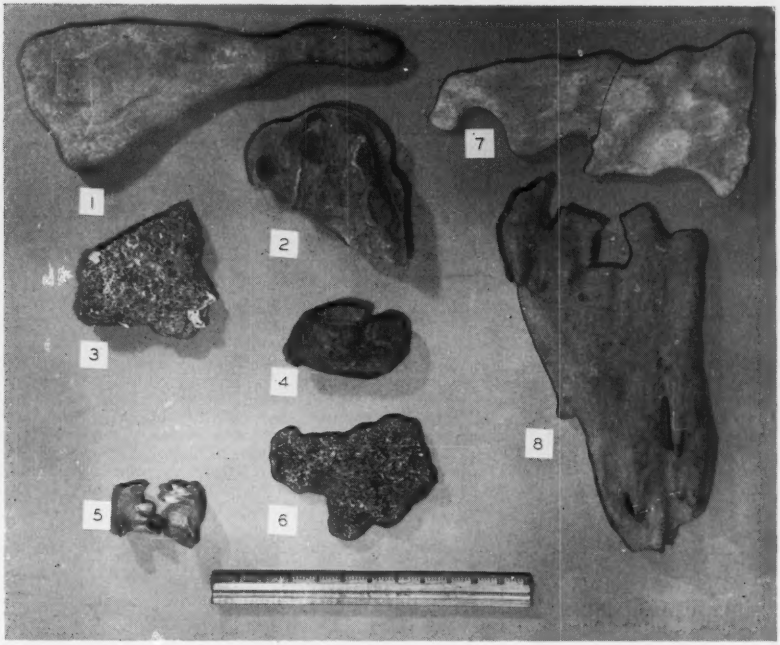

PLATE 1.—Photograph of cemented sandstone slabs. Fig. 1.—Slab of cemented fine sand. Stains indicate iron as a supplemental cementing agent. Fig. 2.—Stratified, cross laminated, cemented sandstone slab. Fig. 3.—Cemented slab consisting predominantly of coquina. Fig. 4.—Clay balls cemented in a matrix of fine sand. Fig. 5.—Interior mold, original shell and exterior mold of modern pelecypods in a matrix of fine sand. Fig. 6.—Cemented sandstone slab incorporating numerous fragments of non-decayed wood. Fig. 7.—Slab of very fine sandstone exhibiting surface ripple marks. Fig. 8.—Slab of fine sandstone exhibiting effects of wind abrasion.

(pl. 1, fig. 1). Many exhibit stratification, consisting of alternating coarser and finer strata. Cross lamination of strata is common (pl. 1, fig. 2). Some consist of cemented shell and coquina (pl. 1, fig. 3). Clay balls cemented in a matrix of fine sand occasionally are found (pl. 1, fig. 4). Modern pelecypods are incorporated into slabs with the formation of complete interior and exterior molds (pl. 1, fig. 5). Extreme rapidity of formation of the slabs is indicated by the incorporation of non-decayed wood fragments in great abundance into the sandstone (pl. 1, fig. 6).

Some of the slabs exhibit an asymmetrically ripple-marked surface (pl. 1, fig. 7). It has not been possible to determine definitely whether these are cemented wind ripples or water ripples. Wind abrasion of the broken slabs results in peculiar shapes indicative of the process (pl. 1, fig. 8).

REFERENCES

RUSSELL, R. J., 1936, Lower Mississippi River delta, reports on the geology of Plaquemines and St. Bernard Parishes: Louisiana Geol. Surv., Dept. of Conserv., pp. 42–72.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 24, NO. 2, PP. 76–99
FIGS. 1–15, JUNE, 1954

SEDIMENTARY FRAMEWORK OF THE MODERN MISSISSIPPI DELTA[1]

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Humble Oil and Refining Co., Houston, Texas
C. R. KOLB
U. S. Waterways Experiment Station, Vicksburg, Mississippi
AND
L. J. WILBERT, JR., Deceased

ABSTRACT

The arrangement of sedimentary units in the birdfoot delta of the Mississippi River is comparable to the structure of a leaf. Present-day facies can be correlated with delta platform deposits obtained from borings. The shape and distribution of sedimentary units, as disclosed from these borings, are shown on maps and sections. Factors controlling delta growth are the load of the river, number of main distributaries of the river, depth of water into which the delta front advances, and subsidence. The rate of lengthening of Southwest Pass, as determined from hydrographic surveys, provides a basis for establishing the rate of bird-foot delta growth and the date when the delta started to form, approximately 1500 A.D. Since then, nearly 27 cubic miles of sediment have accumulated in the delta platform.

INTRODUCTION

The distribution of sediments within the delta of the heavily silt- and clay-laden Mississippi River has been the subject of considerable speculation. The long-held concept of a systematic arrangement of topset, foreset, and bottomset beds, as applied to this delta, was first challenged by Russell and Russell (1939). They pointed out that the sediments of the river mouth region are arranged in leaf-like form, with the deposits of the natural levees and associated channels forming the veins and veinlets, and those of the marshes representing the intervein portions of the leaf blade. They concluded that subsidence and shifting of the river channels, combined with long-continued deposition, have created a "pile-of-leaves" structure beneath the extensive deltaic plain of the Mississippi.

The modern birdfoot delta may be considered the prototype "leaf" from which to explain similar earlier-formed features in the Mississippi River deltaic plain. Information now available permits interpretation of the sedimentary framework of the "leaf"; several borings have been made specifically to test the nature, thickness, and distribution of sediments in the main depositional environments, and additional data have been derived from drilling in connection with oil exploration in the region. The general relationships are shown on the diagram, figure 1.

A preliminary analysis of the framework of the modern delta, recently published as a part of a Mississippi River Commission report (Fisk, 1952, p. 54), indicated that thick, elongate, finger-like deposits of bar "sands" underlie the courses of the principal distributaries. These "fingers," which may be said to resemble the veins of a leaf, are separated by huge clay wedges lying beneath the shallow basins between the distributaries. These findings were among those resulting from an investigation of the problem of Mississippi River diversion directed by Fisk; Kolb and Wilbert supervised the

[1] Read before the Society of Economic Paleontologists and Mineralogists at Houston, March 26, 1953.

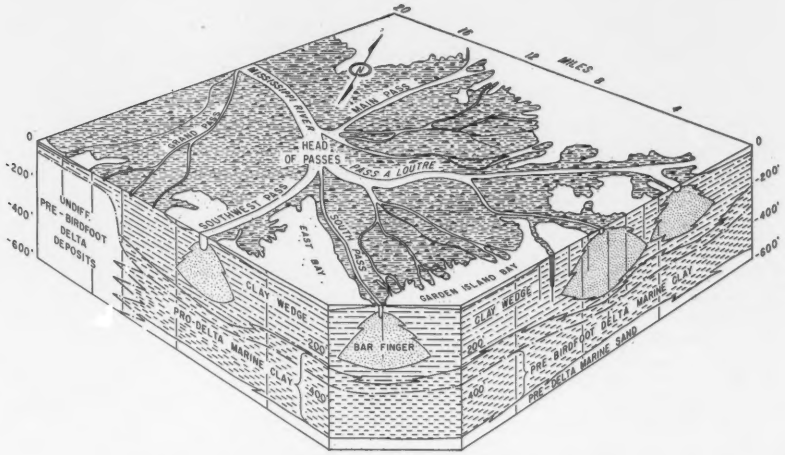


FIG. 1.—Sedimentary framework of the modern, or birdfoot, delta of the Mississippi River.

field work for the investigation and assembled data for the report. Subsequently, McFarlan collected data from additional borings and from offshore samples and did most of the work in connection with the preparation of the present article. The added information has permitted a more accurate correlation between subsurface sediments and sedimentary facies in the existing depositional environments; consequently, the original maps and sections have been revised for this paper. Coordination of data derived from study of surface and subsurface sediments, from topographic and hydrographic surveys, and from estimates of river load has made it possible to establish the rate of delta growth and to evaluate factors controlling it.

Sources of Information and Evaluation of Data

Information used in this report was gathered from many sources, including the publications and files of the U. S. Engineers, and the hydrographic charts of the U. S. Coast and Geodetic Survey. Descriptions and analyses of sediments in several environments were obtained from the comprehensive studies of Trowbridge (1922, 1930) and of Russell (1936), from Russell and Russell (1939), and from a recent report on mudlumps by Morgan (1951). Although detailed faunal analyses are not included in this report, a molluscan fauna from surface and subsurface samples was identified by H. G. Richards, Philadelphia Academy of Natural Sciences, and the microfauna in cores from a boring at Burrwood was identified by M. R. Thomson, Humble Oil & Refining Company. Reference was also made to an unpublished report on the foraminifera of the birdfoot delta region by H. V. Andersen (1951).

Primary sources of the data were samples taken from surface environments on the delta plain, from the Gulf floor, and from shallow borings. Over 60 Gulf floor samples were studied. These were made available by Humble Oil & Refining Company, the U. S. Fish and Wildlife Service, the U. S. Engineers, and by other organizations. The locations and descriptions of 31 bottom samples off Southwest Pass and Pass A Loutre were

TABLE I.—*Principal Mississippi River distributaries*

Passes	Length in miles	Approx. width in feet	Max. thalweg depths in feet	Dredged channel depth in feet	% Miss. River flow	Load (tons per year)
A Loutre	16.4	1600	110	—	37	185,000,000
Southwest	21.2	1600	74	40	29	145,000,000
South	14.2	800	71	30	18	90,000,000

supplied by H. C. Stetson, Woods Hole Oceanographic Institution. A large number of samples were studied from various environments on the delta plain. Several cores of marsh deposits were made available by J. P. Morgan, Louisiana State University.

Data from approximately 375 borings were used to establish the nature and distribution of the sedimentary units within the delta mass. Seven borings were made by the U. S. Engineers to test the composition and thickness of the deposits in the several environments; samples from these borings provided critical data on the characteristics of the sediments. The logs of these borings, several of which were continuously cored to depths of 150 to 200 feet, have been previously published (Fisk, 1952, pl. 34a). Logs of four cored borings were available from other sources, including Trowbridge (1922, fig. 76). Information was also obtained from logs of over 300 wash borings, 150 to 400 feet deep, made for the purposes of geophysical exploration. These logs recorded only major breaks in the section, but it was possible to check their general accuracy by samples from four of the borings. Electric logs from 16 oil wells were available, and the drillers' logs and samples from several other wells were examined.

Prof. J. Laurence Kulp, Lamont Geological Observatory, Geology Department, Columbia University, determined the age of molluscan shells from a mudlump off North Pass by means of Carbon 14 analysis.

The writers consider the findings in this paper as reconnaissance. Although it was possible to establish the general outlines of sedimentary units within the delta, additional data from a much larger number of borings are needed before conclusions can be considered to be fully substantiated. More details of the lithology, structure, and faunal content of existing facies are required for accurate correlations with subsurface sediments. The extensive investigation of Recent sediments being undertaken in the eastern part of the delta region by Scripps Institute of Oceanography under the direction of F. P. Shepard, and the sponsorship of the American Petroleum Institute, should accomplish a great deal toward this end.

THE MODERN BIRDFOOT DELTA

At Head of Passes, 100 miles downstream from New Orleans, the main channel of the Mississippi River divides into three principal distributaries, giving the birdfoot outline to the modern delta (fig. 2). These major distributaries are known as Southwest Pass, South Pass, and Pass A Loutre. Table I presents general information concerning these passes taken from Holle (1952) and the U. S. Engineers (1939). Southeast, Northeast, and North passes branch from Pass A Loutre, complicating the birdfoot pattern. In both Southwest and South passes, however, the flow is confined to single channels and the mouths of both are controlled by jetties built to improve navigation. The South Pass jetties were completed in 1879; those of Southwest Pass, in 1908.

Several minor distributaries above Head of Passes carry about 16 per cent of the flow away from the Mississippi. Main

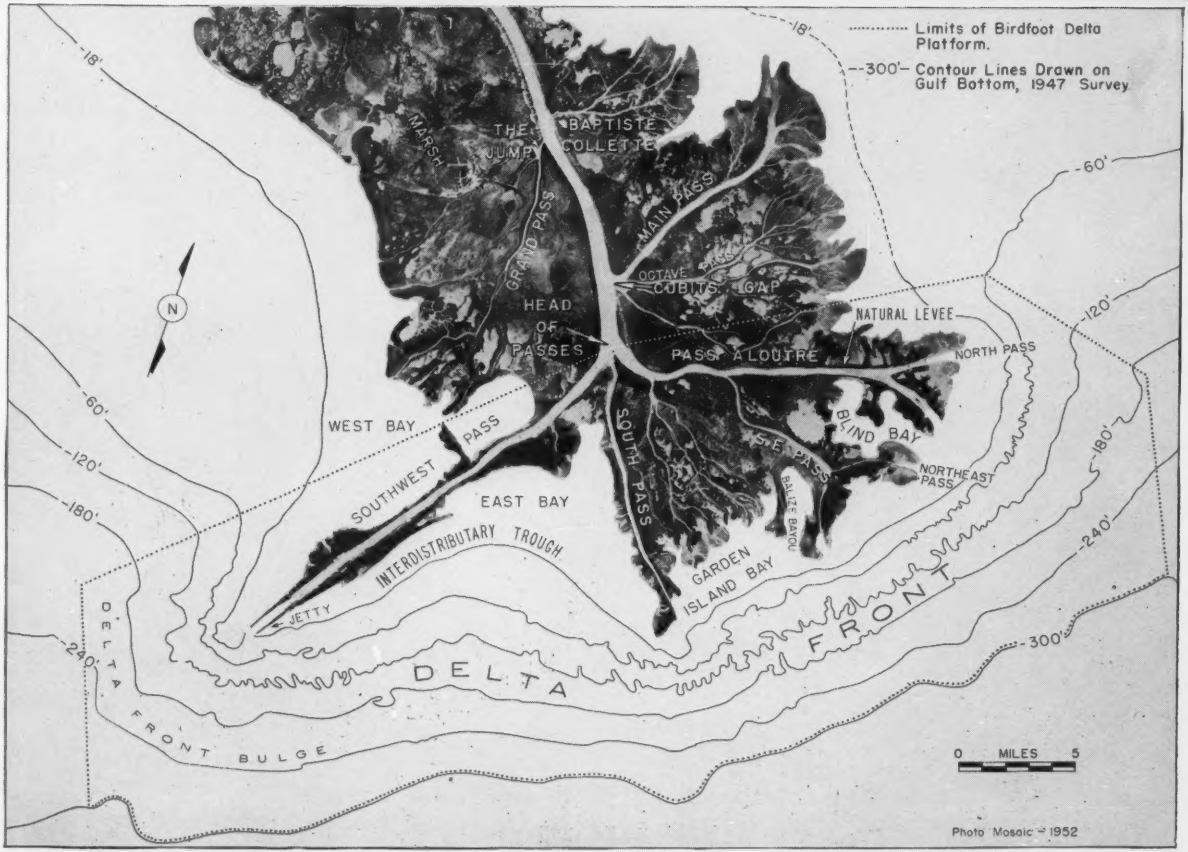


FIG. 2.—Features of the modern, or birdfoot, Mississippi River delta and its platform.

TABLE II.—*Suspended load of the Mississippi River and Passes*
(U. S. Engineers, 1939)

Stream (sample station)	Stage	Discharge c.f.s.	Sand %	Silt %	Clay %	Load, tons per day
Mississippi River	1	394,000	5	31	64	750,000
Mile 6.3 A.H.P.	2	859,400	8	44	68	1,760,000
Pass A Loutre	1	176,000	5	30	65	370,000
Mile 1 B.H.P.	2	388,700	9	46	45	870,000
Southwest Pass	1	159,800	5	27	68	285,000
Mile 3.2 B.H.P.	2	325,900	6	46	48	615,000
South Pass	1	58,300	4	36	60	173,000
Mile 3.8 B.H.P.	2	144,800	9	40	51	276,000

1—Low Stage, July 13, 1938.
2—High Stage, April 26, 1938.
A.H.P.—Above Head of Passes
B.H.P.—Below Head of Passes

Pass and Octave Pass branch from the east bank of the river at Cubits Gap, three miles upstream from Head of Passes, and Baptiste Collette Bayou, at 10 miles upstream. On the western side of the river, Spanish, Tiger, and Grand passes diverge from the channel at The Jump, near Venice, approximately nine miles above Head of Passes. Although these distributaries are a part of the modern delta, they are of very recent development and, for purposes of this report, the upstream limit of the birdfoot delta is placed at Head of Passes.

The birdfoot delta is only the subaerial expression of a broad platform built onto the Gulf floor, the development of which has created a 50-mile-wide protuberance on the continental shelf. The platform, as outlined on figure 2, covers an area of approximately 700 square miles, and its seaward margin is in places a part of the continental slope. The portion of the platform inside the 18-foot Gulf bottom contour contains approximately 290 square miles; of this area, the subaerial portion includes 131 square miles. The outer limit of active sedimentation, the seaward limit of the delta platform, is considered to be near the 300-foot contour.

THE LOAD OF THE MISSISSIPPI RIVER AND ITS PASSES

A knowledge of the character of the load of the Mississippi River is essential to an understanding of the nature and distribution of the deltaic deposits. Systematic sampling and analysis of the suspended load of the river and of each of its main passes by the U. S. Engineers (1939) has yielded a great deal of significant information. From these and more recent observations, Holle (1952, p. 123) estimated that an average suspended load of 400 million tons is transported annually to the Gulf. The quantity of bed load was not measured but, from other data, he assumed that it was 25 per cent of the suspended load. The total load of the Mississippi River was, therefore, estimated to be approximately 500 million tons a year.

The larger portion of the river's load consists of fine silt and clay particles. Small percentages of fine and very fine sand are present, but grains coarser than fine sand are rare. The analyses of suspended load made by the U. S. Engineers (1939), which are tabulated in table II, permit comparison of the load transported by the Mississippi River and by each of its principal passes during a relatively high and a relatively low stage of the river. The samples for each stage were collected on the same day; the same discharge ranges were used for sampling the streams during high and low stages. As can be seen in table II, the percentage of sand, silt, and clay carried in suspension by each of the distributaries varies slightly for a given stage of the river. It

TABLE III.—*Bed load of the Mississippi River and passes* (U. S. Engineers, 1939).

Stream (sample station)	Discharge c.f.s.	Fine sand %	V. Fine sand %	Silt %	Clay %
Mississippi River (Mile 8, A.H.P.)					
5-21-38	546,100	86	14	—	—
6- 7-38	687,200	57	5	5	33
6-13-38	732,500	84	5	3	8
Southwest Pass (Mile 3, B.H.P.)					
5-21-38	175,900	78	5	3	14
6- 7-38	236,000	35	4	8	53
6-13-38	237,800	76	7	3	14
South Pass (Mile 3, B.H.P.)					
5-21-38	78,900	87	3	1	9
6- 7-38	113,000	100	—	—	—
6-21-38	110,200	77	6	1	16

A.H.P.—Above Head of Passes
B.H.P.—Below Head of Passes

will be noted, however, that the percentage of both sand and silt carried by each of the streams increased during the high stage. The average suspended load is approximately 7 per cent sand, 38 per cent silt, and 55 per cent clay.

Very few bed load measurements have been made for streams in the delta region. Table III presents analyses made by the U. S. Engineers (1939) of samples collected at Southwest and South passes, and on the Mississippi. Samples were taken at the same locality during three different stages. A wide variation in the percentage of different types of bed load will be noted, as will the fact that, like the suspended load, no particles coarser than fine sand are recorded.

DEPOSITIONAL PROCESSES AND ENVIRONMENTS

Sediments carried to the delta are deposited onshore within several environments of the delta plain and offshore as stream mouth bars; they are also deposited within the extensive pro-delta zone of the delta front and Gulf floor. The onshore environments (fig. 2) include the distributary channels with their associated natural levees and marginal marshlands. Between the distributaries are shallow-water basins, the inter distributary troughs, which are largely covered with lakes and bays; in places the troughs hold extensive marshlands and, near their seaward margins, sand spits and subaqueous bars. The general configuration of the main environments is illustrated on figure 3, a map of the western half of the delta platform as it existed in 1874, before the construction of the Southwest Pass jetties.

As sediments have reached the sea, the most active deposition has occurred close to the mouths of the distributaries and has created bulges on the front of the delta platform. These submarine features resemble subaerial alluvial fans, with slopes radiating from the stream mouth as from the apex of a cone; the Southwest Pass bulge has a radius of more than three miles and affects the bottom contours to a depth of over 240 feet. Inasmuch as Pass A Loutre divides into several minor distributaries, the discharge at each mouth is relatively small and bulges are not well developed along the eastern front of the delta (fig. 2).

The greater part of the sand and silt load of the river is deposited as distributary mouth bars on the upper part of the bulges, where the velocity of the stream is checked as it enters the sea. Most rapid bar building occurs during rising

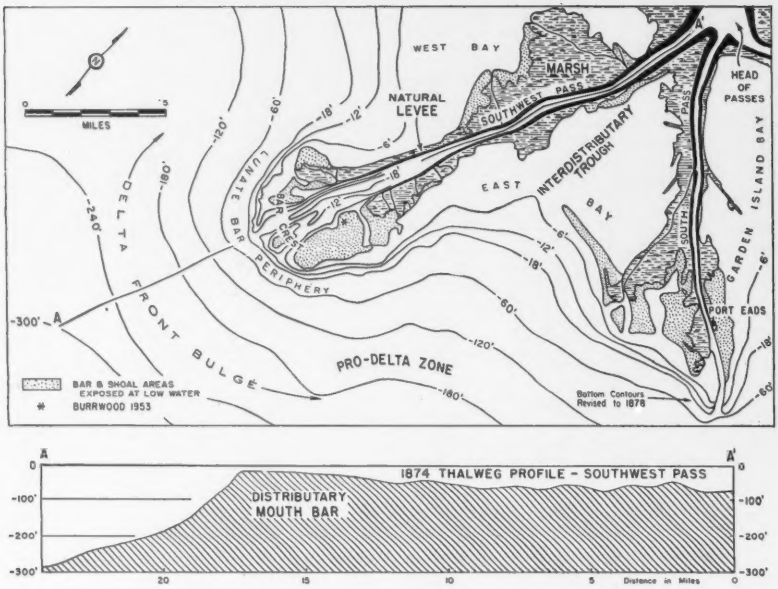


FIG. 3.—Principal environments of deposition within the southwestern section of the birdfoot delta in 1874, prior to construction of the Southwest pass jetties.

and falling high river stages; dredging is then necessary to maintain a navigable channel across the bar. Sediments accumulate on the bar crest and also at the ends of the submerged channels, where they form a continuous unit peripheral to the crest (fig. 3). The outer bar unit extends to depths varying between 50 and 100 feet, and its frontal slope is somewhat steeper than slopes on the lower parts of the bulges. When viewed in plan, the entire bar is lunate, or crescent-shaped,[2] with its distal ends feathering out around the river mouth.

The fine silts and clays are carried seaward from the mouths of passes for considerable distances as vast plumes of turbid water and are deposited in the prodelta environment. (See photograph, fig. 4.) According to Scruton and Moore (1953, p. 1074), muddy water often extends seaward for as much as 65 miles. Measurements of density, chlorinity, and turbidity (Bates, 1953) show that the plumes have a maximum thickness of 15 feet at the mouths of passes and thin seaward. A large proportion of the sediments which flocculate from the plumes are deposited around the toes of the distributary mouth bars, forming the basal part of the bulge. Much of the remaining load is deposited on the Gulf floor, but some is swept inshore by marine currents and reaches the interdistributary troughs.

The passes are remarkably straight and have lengthened seaward across their stream mouth bars, scouring their channels in these sandy deposits. The chan-

[2] In theorizing on the origin of such lunate bars, Bates (1953) applied principles of jet flow and explained that they develop under conditions of hypopycnal inflow where sediment-laden fluid moves out over the surface of denser oceanic waters.

FIG. 4.—Plume of turbid water extending southwestward from mouth of Southwest Pass, March 28, 1953.

nels are deepest upstream near Head of Passes and shoal seaward. They maintain a nearly constant width except at their mouths where they widen abruptly into a typical bell shape over the crest of a bar (fig. 3). During low stages of the river, salt water intrudes the channels and extends upstream beyond Head of Passes as a thick wedge, above which the fresh water moves seaward. It is during the low stages that the deeper parts of the channel thalweg may become filled with a coagulated mass of sludge consisting of clays, silts, and fine sands (Holle, 1952, p. 125).

Natural levees form during flood stages, when the river tops its banks and drops part of its load near the channel. At Head of Passes, the levees are five to six feet high, approximately 1000 feet wide, and are covered with willows and oaks. Because the levees have developed concurrently with channel lengthening, they are smaller downstream along more recently developed segments of the channels; near the bar, they are barely distinguishable from the marshes and support only a growth of cane and marsh grasses. (See photograph, fig. 5.) Their submarine counterparts are found as bars flanking submerged channels (fig. 3).

Sediments swept over the natural levees during flood are carried into the shallow-water basins of the interdistributary troughs. Some of the floodborne materials may collect in the marshlands at the trough margins and some may be deposited in the central, deeper parts of the trough, or be carried by currents to the delta front. Wave and current action winnows fine particles from bay bottom sediments, leaving coarser particles to

FIG. 5.—Cane-covered natural levees and marginal marshes near end of Southeast Pass.

floor parts of the bays, or gathers some of the sands and silts to form spits and subaqueous bars. A sand spit development on the eastern side of Southwest Pass near Burrwood is shown on the photograph (fig. 6). Subaqeuous bars close to the seaward margin of the East Bay trough, west of the mouth of South Pass, are shown on figure 3.

Extensive marshland tracts have developed in some of the troughs as a result of crevassing of distributaries during flood. The marshes in Garden Island Bay, shown on the air photo mosaic (fig. 7), have formed since 1891, when the crevasse of Pass A Loutre enlarged rapidly. Distributary channels branching from the crevasse outlet have developed an anastomosing network of streams, including Cadro, Dennis, and Wright passes. These closely-spaced streams build coalescing subaqueous deltas of silty sand and sandy silt which form a continuous bay bottom frontal slope to the marshlands (fig. 7). During low tide, when the marsh front is exposed, various grasses and sedges, such as alligator grass, three-corner grass, cattails and cane, start to grow (O'Neil, 1949). This vegetation traps silts and clays brought in during flood and helps to build the marshlands. In some areas, compaction of the sediments beneath marsh deposits leaves bodies of floating marsh, or flotant (Russell, 1942).

SEDIMENTARY FACIES

Characteristics of sedimentary facies in the several main environments of deposition were determined from grain-size analyses, from examination of bedding and other structures seen in cores, and from identification of associated fauna. The number of samples available for study was too small and the locations too widely distributed to permit detailed mapping of the facies in each environment. A generalized map (fig. 8) showing

FIG. 6.—Sand spit development near Burrwood on east flank of Southwest Pass.

the distribution of the facies could be prepared, however, by grouping the sediments into the following four lithologic types: sand and silty sand, sandy silt and clayey silt, silty clay, and clay.

The map (fig. 8) indicates a direct relationship between sediments and environments of deposition on the delta front. The correlation is particularly clear where each of the lithologic types outlines the bulges and, in so doing, crosses depth zones of the Gulf. Similar close correlations can be drawn between sediments and environments of the onshore facies of the delta plain. There are, however, anomalous relationships, such as the broad expanse of sandy silt which floors the Gulf west of Southwest Pass.

Bar Facies

Deposits on the surface of the bulges at the mouths of distributaries form gradational sequences in which the median grain diameter of constituent particles becomes smaller as distance seaward from the bar crest increases. Fine sands at the crest of each distributary mouth bar are replaced downslope by very fine sands which are succeeded at greater depths by silt; near the toe of the bulge, clays replace the silts. The bar facies of this gradational sequence of deposits includes only the materials containing sands; these are found in the zones of sand and silty sand, and sandy silt and clayey silts shown on figure 8. Sediments of these facies are referred to as bar "sands" to distinguish them from the pro-delta silty clays and clays which occur on the lower parts of the bulge.

Cumulative grain-size curves for samples of bar "sands" taken at various positions down the slope of the Southwest Pass bar bulge are shown on figure 9A. Well sorted, unfossiliferous, fine-grained sands, with less than 10 per cent silt, make up the bar at its crest. At a depth of 50 feet, the sands are very fine-grained, and the deposits include 35 per cent silt and less than 5 per cent clay. The deposits become less well sorted, and the percentage of sand decreases markedly below 50 feet, as clays become more amd more abundant. At 100 feet, the bar contains only 10 per cent very fine sand, 60 percent silt, and 30 per cent clay; at 150 feet,

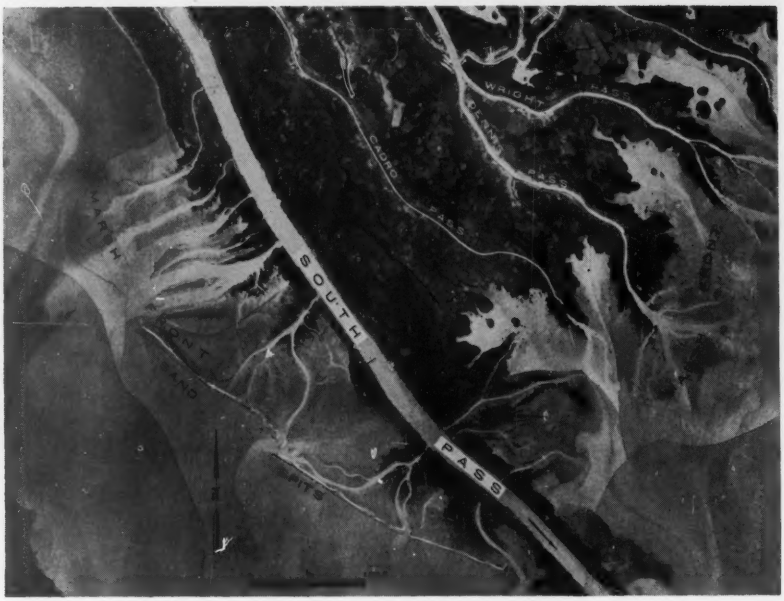


FIG. 7.—Air photo mosaic (Dec. 1951) of segment of South Pass and adjacent interdistributary troughs. Marshlands east of the pass have developed rapidly since the crevasse at Pass A Loutre began to enlarge rapidly in 1891.

there is less than 5 per cent very fine sand, and approximately equal parts of silt and clay. There is no sand in samples taken from depths of about 200 feet, and, in the absence of more precise data, the base of the bar "sands" facies is placed at approximately 150 feet. Analyses of sediments from the South Pass and North Pass bars, also shown on figure 9A, confirm the existence of relationships similar to those of the Southwest Pass bar facies.

Cores from the boring at Burrwood indicate that "sands" of the bar facies are approximately 250 feet thick. They are massive and locally cross-bedded near the top of the section, but at depth they consist of alternate thin layers of very fine silty sand and silty clay with occasional dark organic-rich clay laminae. The photograph (fig. 10C) illustrates some of the characteristics of these facies, and cumulative grain-size curves are shown on figure 9B.

Pro-delta Facies

Sediments of these facies form a belt of fine-grained deposits covering the delta front and the surrounding Gulf floor. They are arbitrarily divided into an inner and outer zone by the line between silty clays and clays shown on the map (fig. 8); in the bulge areas, they grade into the bar "sands." Cumulative grain-size curves for samples collected from these facies at depths of 220 and 380 feet off South Pass and at depths of 152, 218, and 287 feet off Southwest Pass are presented on figure 9C.

The silty clay deposits of the inner zone are dark-colored and well-bedded. In the

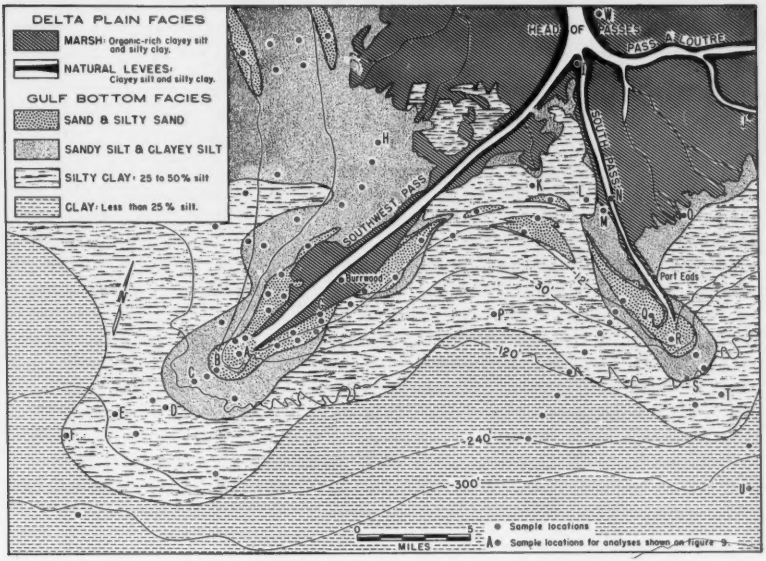


FIG. 8.—Generalized distribution of facies within the southwestern portion of the birdfoot delta platform.

section which is transitional with the bar "sands," layers of sandy silt and silty clays alternate. The facies become more homogeneous with depth and hold only minute lentils of sandy silt in the lower part of the section. The inner zone deposits are only sparingly fossiliferous; echinoids are present, as are ostracoda and foraminifera of the genera *Cibicides*, *Globorotalia*, *Robulus*, and *Uvigerina*. Scattered specimens of the pelecypod *Mulinia* are found.

The clays of the outer zone are homogeneous and well-bedded and hold an abundant marine fauna: pelecypod genera include *Arca*, *Cardium*, *Chione*, *Mulinia*, *Nuculana*, and *Phacoides*. The gastropods commonly represented are *Crepidula*, *Fasciolaria*, *Natica*, *Olivella*, *Phalium*, and *Polinices*. Scaphopods, bryozoa, echinoids, and ostracods are abundant. Common foraminifera include *Bigenerina*, *Elphidium*, *Marginulina*, *Nonion*, *Nonionella*, *Quinqueloculina*, *Rotalia*, and *Textularia*.

Channel Fill, Natural Levee, and Marsh Facies

Some of the minor distributaries have been abandoned and their channels plugged as flow has diminished. Cores from the Bayou Balize (fig. 2) channel filling reveal that the lower part of the channel is filled with massive, fine to very fine, unfossiliferous sand beds. (See log of boring MD-6, Fisk, 1952, pl. 34a.) These grade into an overlying upper section of bedded sands, sandy silts, and, near the surface, silty clays which contain a typical marsh fauna.

Natural levee deposits form one of the more distinctive groups of sediments in the deltaic plain. They consist of well-bedded, unfossiliferous, clayey silts and

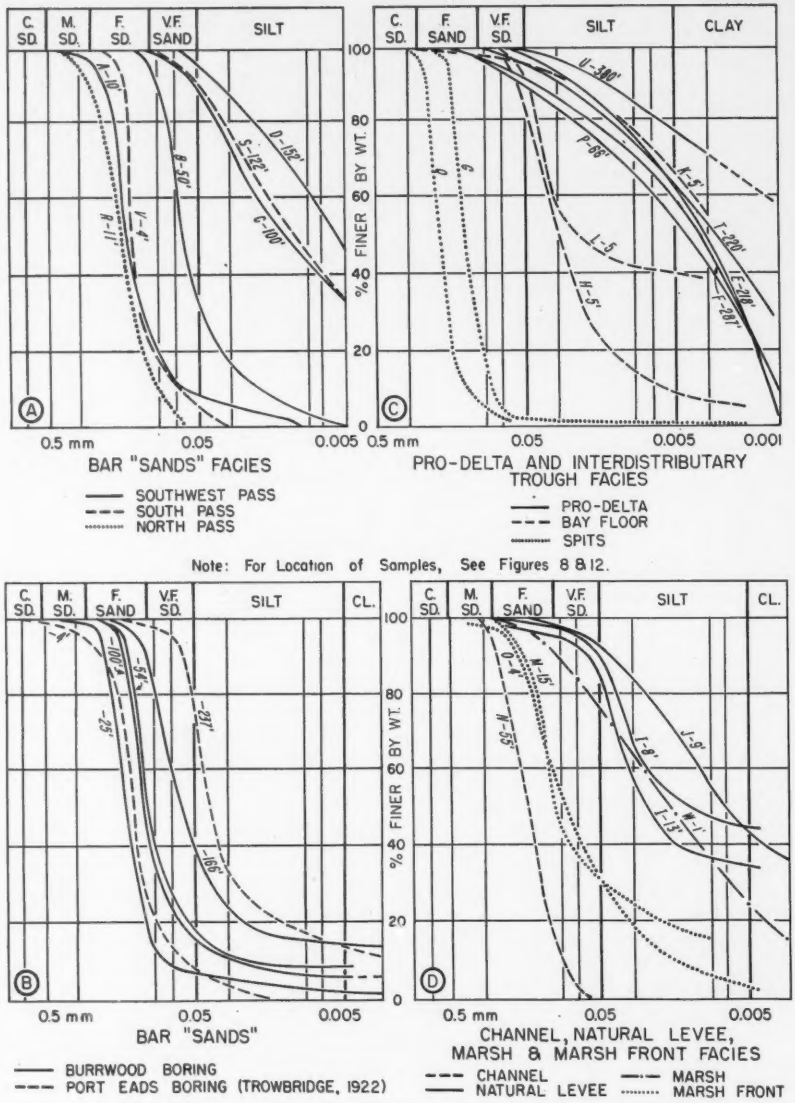


FIG. 9.—Cumulative curves for selected surface and subsurface samples representative of various sedimentary facies from the birdfoot delta.

silty clays laid down during seasonal floods. In their initial stages of development, they are built directly on the stream mouth bar deposits. Basal sediments in the levees are, therefore, transitional with the bar "sands." In their later stages of growth, they are built above marsh level and support vegetation. During the dry season, they develop shrinkage cracks along which sediments become slightly oxidized. Cumulative grain-size curves of levee deposits are shown on figure 9D.

Massive, organic-rich clayey silts and silty clays characterize the marsh facies. In their typical development, marsh deposits form a soft spongy mass, brown to black in color and one to three feet thick, in places made up largely of grass roots. (See photograph, fig. 10A.) The marsh deposits grade laterally into the natural levee and bay bottom sediments. A grain-size analysis of a sample from the marsh 1.5 miles southeast of Head of Passes is shown on figure 9D The marsh sediments contain ostracods, the remains of fiddler crabs and crayfish, as well as the gastropods *Littorina* and *Neritina*.

Interdistributary Trough Facies

Sediments of several types make up the trough facies; layered sandy silts and clayey silts veneer marginal sections of the bay bottoms and massive, poorly sorted, silty clays floor deeper parts of the bays. Shallow-water crevasse deposits of the marsh front are distinctive; they consist of layers of cross-bedded sandy silts and fine sands interbedded with clayey silts. (See photograph, fig. 10D.) Spits and subaqueous bars are made up of clean, well sorted, fine sands which grade into marginal zones of silty sands. Cumulative grain-size curves of typical samples from some of these deposits are illustrated on figures 9C and 9D. The faunal content of the trough sediments, exclusive of the spits and subaqueous bars, is typical of brackish-marine bays described by Lowman (1949, p. 1953). They contain a restricted assemblage of foraminifera, including the genera *Elphidium*, *Rotalia*, and *Trochammina*. *Ostrea*, *Mulinia*, and *Mytilus* are common pelecypods. The spits and bars hold a fauna similar to to that of the surrounding bays, but they also hold shallow-water marine organisms, such as the clams *Arca*, *Barnea*, and *Donax*, and the snail *Natica*.

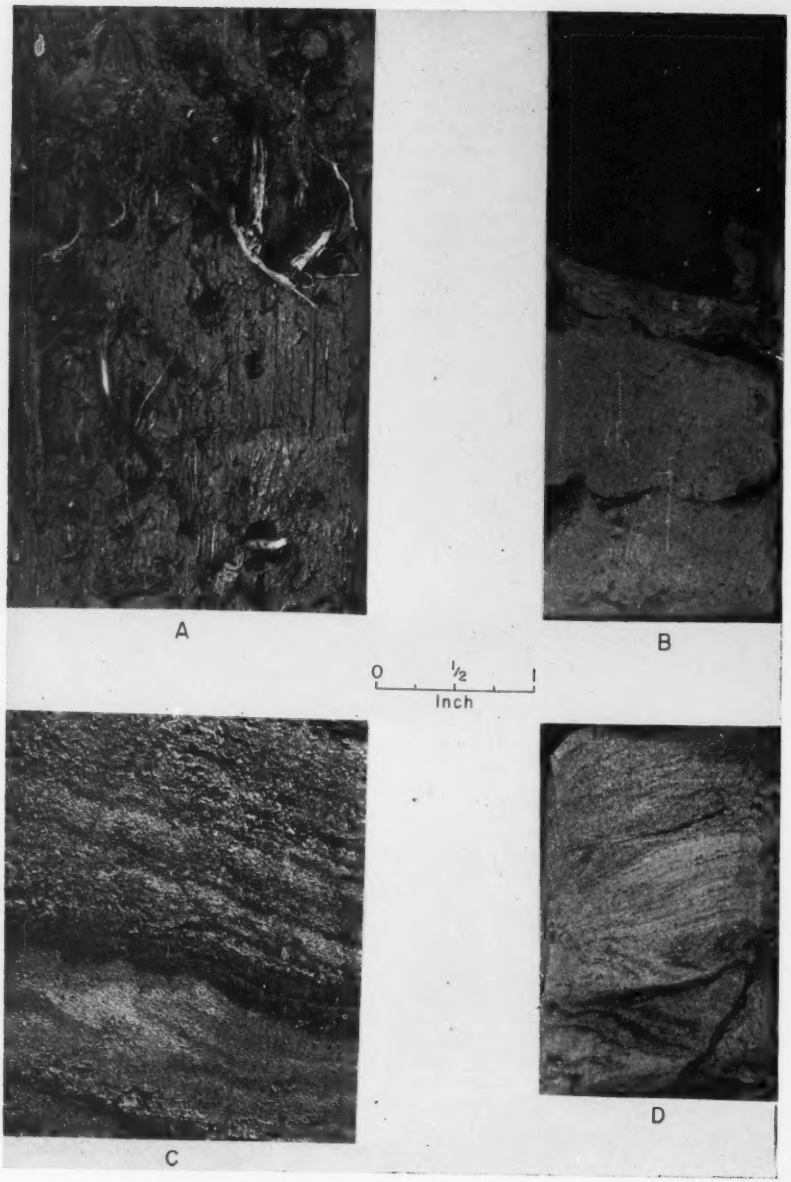
SEDIMENTARY UNITS OF THE DELTA PLATFORM

The delta platform is made up of elongate fingers of bar "sands" underlying the distributaries, and of wedges of silty clay beneath the interdistributary troughs and delta front. A minor thickness of the underlying pro-delta clay layer is included in the platform because the distributary mouth bulges extend to a depth of about 300 feet. These clays, present only at the base of the platform, are part of the thick, widespread, prodelta marine clay layer which accumulated in large part before the development of the birdfoot platform.

Although the natural levee deposits belong to a different facies, they rest directly upon the bar "sands" and are considered here as part of the bar finger sedimentary unit. The deltaic mass of the platform also holds anomalous mudlump structures, which, as far as is known, are unique to the birdfoot delta. The general nature and distribution of the sedimentary units are shown on the diagram (fig. 1).

Bar Fingers

The skeletal elements of the delta platform are the four- to five-mile-wide bar "sands" fingers which diverge from Head of Passes and extend to the delta front bulges, where they underlie the distributary mouth bars. The contour map (fig. 11) shows the elevation and configuration of their top surface which slopes symmetrically away from the distributary channels. The fingers reach a measured maximum thickness varying from 250 feet at Burrwood on Southwest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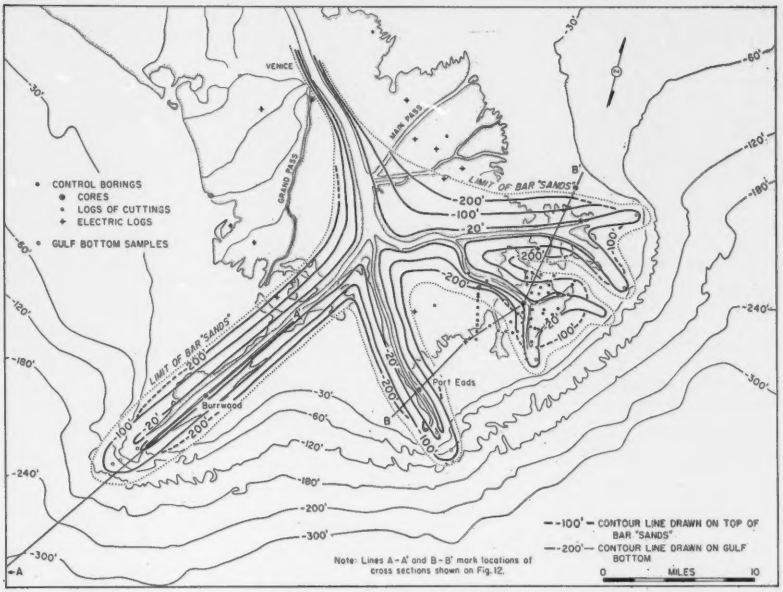

FIG. 11.—Bar fingers of the birdfoot delta platform. Contours show depth to top of the bar "sands" facies.

Pass to 300 feet near the end of Southeast Pass. (See cross sections A-A′ and B-B′, fig. 12.) The longitudinal section of the Southwest Pass finger indicates an abrupt seaward decrease in thickness beneath the distributary mouth bar.

Cumulative grain-size curves (fig. 9B) indicate that in the bar fingers both the median grain-size and degree of sorting decrease with depth as they do on the modern distributary mouth bars. Analyses of a core from 166 feet in the Burrwood boring reveal sediments comparable to those at −50 feet on the slope of the Southwest Pass bulge. Fairly well sorted sediments from a sample at 237 feet in the Port Eads boring (Trowbridge, 1922, fig. 76) contain 23 per cent very fine sand, 62 per cent silt, and 15 per cent clay. These finger deposits probably accumulated higher on the bar slope than their present depth would indicate, since a sample from existing bar "sands" facies at South Pass from a depth of 122 feet is finer and contains approximately 10 per cent very fine sand, 55 per cent silt, and 35 per cent clay.

The natural levees are wedge-like

FIG. 10.—Photographs of cores showing structures characteristic of several delta facies. A—Organic-rich, silty clay marsh deposits near Cubits Gap, sample W, fig. 8. B—Well bedded prodelta sandy silts and silty clays from depth of 140 feet in Garden Island Bay. (See log of MD-4 boring, Fisk, 1952, pl. 34a.) C—Thinly bedded bar "sands" facies from oriented core at depth of 122 feet in Burrwood boring. D—Cross-bedded, marsh-front sandy silts at depth of 27 feet in same boring as B.

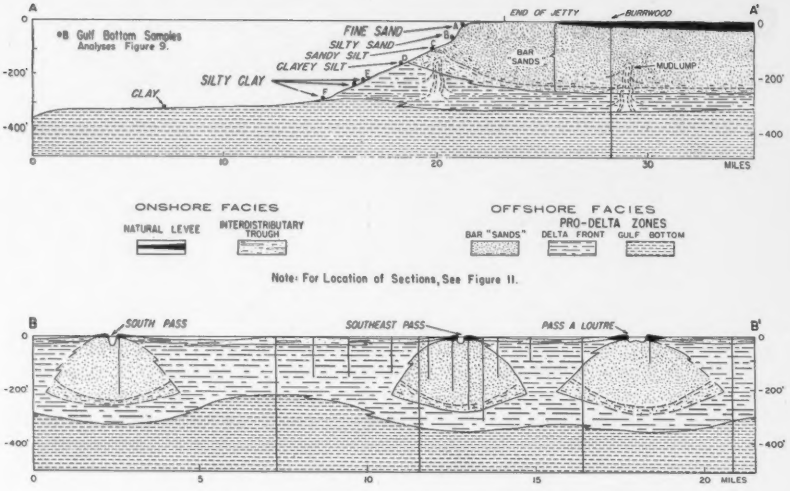

FIG. 12.—Cross sections showing principal sedimentary units of the birdfoot delta platform.

masses which reach an average maximum thickness of 20 feet near the distributary channels; although they rise only a few feet above sea level, their base may be many feet below it. The levee sediments grade laterally into the marsh deposits and downward into the bar "sands."

Clay Wedges

In plan view, the delta platform is segmented by the bar fingers into pie-shaped wedges. The interdistributary trough and delta front deposits comprising the wedges narrow with depth since they overlap the downward-widening bar fingers; the narrowest part of the wedge section is at a depth of approximately 200 feet (fig. 12). Minor lenticular bodies of sand and silt, marking the positions of spits, bars, and crevasse deposits are present in the upper part of the wedges, but the lower section consists of silty clays in which the percentage of clay increases with depth in much the same way as it does on the Gulf floor at increasing distance from the delta front.

Pro-delta Marine Clay Layer

The basal unit of the deltaic mass is the thin upper part of a pro-delta marine clay layer known to be approximately 300 feet thick throughout the delta area (fig. 1). The entire layer overlies a fossiliferous shallow-water marine sand of post-Pleistocene age which was deposited when sea level was somewhat lower than at present. From available information it is not possible to determine accurately the thickness of the marine clay which has accumulated during the period of growth of the birdfoot delta, but it is thought to be less than 75 feet thick.

Mudlumps

Mudlumps are deformed masses of clay which have intruded the bar fingers and occur as small islands in the Gulf near the mouths of the distributaries, or as low mounds in the closely adjacent marshlands. Many are structurally active features with associated mud "volcanoes," gas seeps, and springs. The

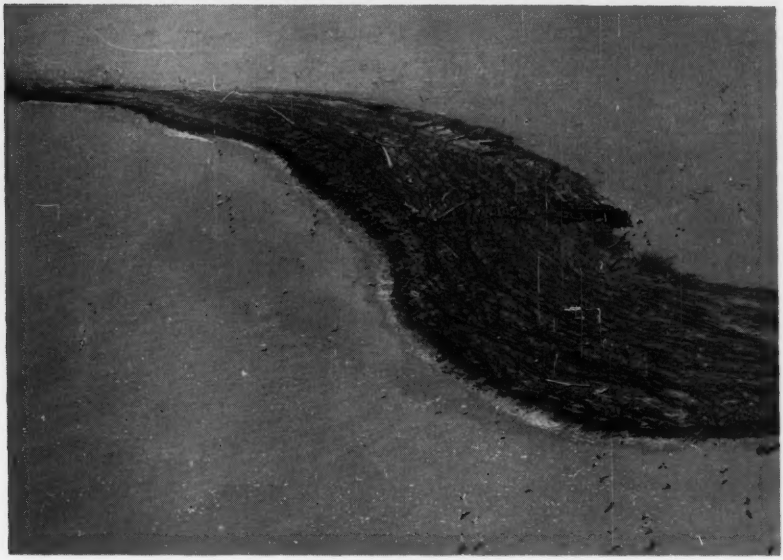

FIG. 13.—Mudlump island approximately 200 feet wide and 600 feet long lying 1 mile east of the mouth of north Pass. (Airphotograph by U. S. Engineers, April, 1948.)

lumps vary greatly in size; some are very small; others occupy areas an acre or more in extent and may reach an elevation of 10 feet above sea level. Many of them, such as the highly folded and faulted one off North Pass, shown on the photograph (fig. 13), have an elongate sigmoidal shape.

Mudlumps have been described by several writers, including Hilgard (1871), Shaw (1913), and Russell (1936). Recently, a detailed study of the nature, distribution, and origin of mudlumps was made by Morgan (1951), who confirmed earlier observations that their growth is most active during periods of high river stage, when large amounts of sand and silt are added to the distributary mouth bars. Morgan concluded that the load of a stream mouth bar causes the underlying clay to be deformed and to be forced upward into the bar deposits. Submarine mounds on the slopes of the bars of Southwest and South passes were interpreted as representing initial stages in mudlump development. As the bar deposits continue to accumulate and to extend seaward, the load on underlying beds increases and clay may continue to be intruded until it reaches the surface and its growth becomes stabilized in the mudlump.

Oriented cores from a section extending from 85 to 167 feet in the Burrwood boring disclosed thinly bedded bar sediments (fig. 10C) with a uniform dip of 14° south. The dips are not related to cross bedding and are too steep to be representative of depositional dip on the bar slope. It is concluded, therefore, that they reflect the effects of mudlump deformation.

Based on a study of included microfauna, Andersen (1951, pp. 23–24) concluded that clays in different mudlumps were forced upward from varying depths.

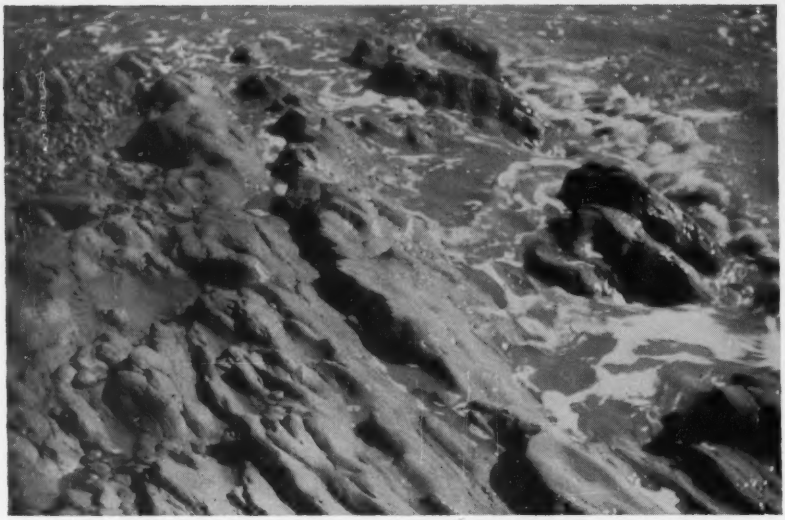

FIG. 14.—Steeply dipping, well bedded, pro-delta marine clays exposed on the flanks of the mudlump shown on figure 13. Width of foreground is approximately 6 feet.

In some of the mudlumps he found clays with marine faunas which include foraminifera found living on the Gulf floor only at depths below 400 feet. Other mudlumps, however, are made up of silty clays containing foraminifera which live in shallower Gulf waters. Molluscan faunas collected from mudlumps off North Pass in connection with the present investigation were identified by Richards (personal communication) and found to be similar to those from below 300 feet in the pro-delta marine beds penetrated in the Burrwood boring. Tilted strata around the margins of some of the lumps, such as shown on the photograph (fig. 14), provide excellent exposures of pro-delta marine clay facies.

DEVELOPMENT OF THE DELTA PLATFORM

The nature and distribution of sedimentary units within the modern delta indicate that facies relationships comparable to those seen in existing sedimentary patterns have remained essentially constant throughout the period of delta platform enlargement. The principal factors which control the shape and growth of the delta platform are the load of the river, the number of main distributaries diverging from Head of Passes, the depth of water into which the delta front advanced, and the amount of subsidence. There is no evidence that these factors have varied in importance since the platform started to form. Consequently, it can be assumed that depositional processes and the rate of platform growth have proceeded uniformly.

Subsidence

Evidence of subsidence in the birdfoot delta has been cited by Russell (1936, pp. 162–179), who determined that objects such as section-corner-markers, tide gauges, and cemetery vaults are sinking at a rate varying up to 0.9 feet a year. He concluded that subsidence may be caused

by a number of factors, including compaction and structural downwarping. There are insufficient data available to estimate the amount of downwarping in the local area of the birdfoot delta, but the amount of subsidence resulting from compaction can be established.

The most pronounced effects of compaction are seen in the bar fingers and the natural levees, which change in shape and in elevation both while deposition is taking place and after burial. Well sorted sands within the Southwest Pass bar finger were found to extend to a depth of 166 feet in the Burrwood boring. Because similar sands are found on the bar front at a depth of approximately 50 feet, the amount of subsidence which took place contemporaneously with deposition on the central part of the bar must have been in excess of 100 feet. A complementary amount of thinning has taken place in the pro-delta silty clay unit which is 200 feet thick on the Southwest Pass bulge, and is but 100 feet thick beneath the bar finger (fig. 12). The longitudinal section of the Southwest Pass finger also shows a marked thinning of the bar "sands" between Burrwood and the toe of the bar on the bulge. Much of this thinning is considered to reflect the effects of compaction of the underlying silty clay unit during bar sedimentation. Incipient mudlump mounds on the bar slope, as reported by Morgan (1952, pp. 140–141) also support the view that a large amount of vertical adjustment occurs at sites of bar deposition.

Compaction in sediments beneath the bar fingers continues, however, after bar growth has been completed, as is demonstrated by the fact that the bases of natural levees have subsided to an average elevation of 20 feet below sea level. The levee sediments grade downward into the bar "sands," and their basal elevation is, therefore, a measure of the subsidence which has taken place after formation of the bar fingers. Much of this subsidence occurs close to the river mouth while natural levees are developing. At Burrwood, only five miles above the stream mouth, borings show the base of the levees to be at their maximum depth of 22 feet (fig. 12).

The elevation of the lateral margins of the bar fingers also demonstrates the amount of post-depositional subsidence. The toe of the existing bar facies, the outer limit of deposition of sandy sediments, occurs in a belt around the distributary mouths at a uniform depth of approximately 150 feet. In the subsurface, however, the outer limit of sandy facies in the bar finger, as noted on the cross section (fig. 12), is over 200 feet below the surface, indicating more than 50 feet of post-depositional subsidence.

Very little accurate information was available from borings to determine the amount of compaction in the interdistributary troughs. Organic-rich marsh sediments were cored to a depth of 28 feet in a boring made in the Garden Island Bay trough. Since marsh deposits are laid down close to sea level, their presence at depth reflects the amount of compaction of the underlying sediments. Some local marshlands, mapped on early surveys of the delta, are shown on later surveys as bay bottom (fig. 15), indicating that compaction in the clay wedges resulted in subsidence which brought about local inundation of the marshes.

Growth of the Delta Platform

Hydrographic surveys afford a basis for computing the rate of growth of the delta platform. The map (fig. 15) indicates the position of selected Gulf floor contours as determined by the surveys of 1838, 1865, 1886, and 1947. The seaward progression of the contours, which is particularly pronounced in the bulge areas, indicates that delta enlargement affects the Gulf bottom to depths of over 300 feet. The rate of delta growth can best be computed from the rate of lengthening of Southwest Pass, which has maintained a single channel throughout its development. Neither Pass A Loutre nor South Pass can be used satisfactorily to evaluate

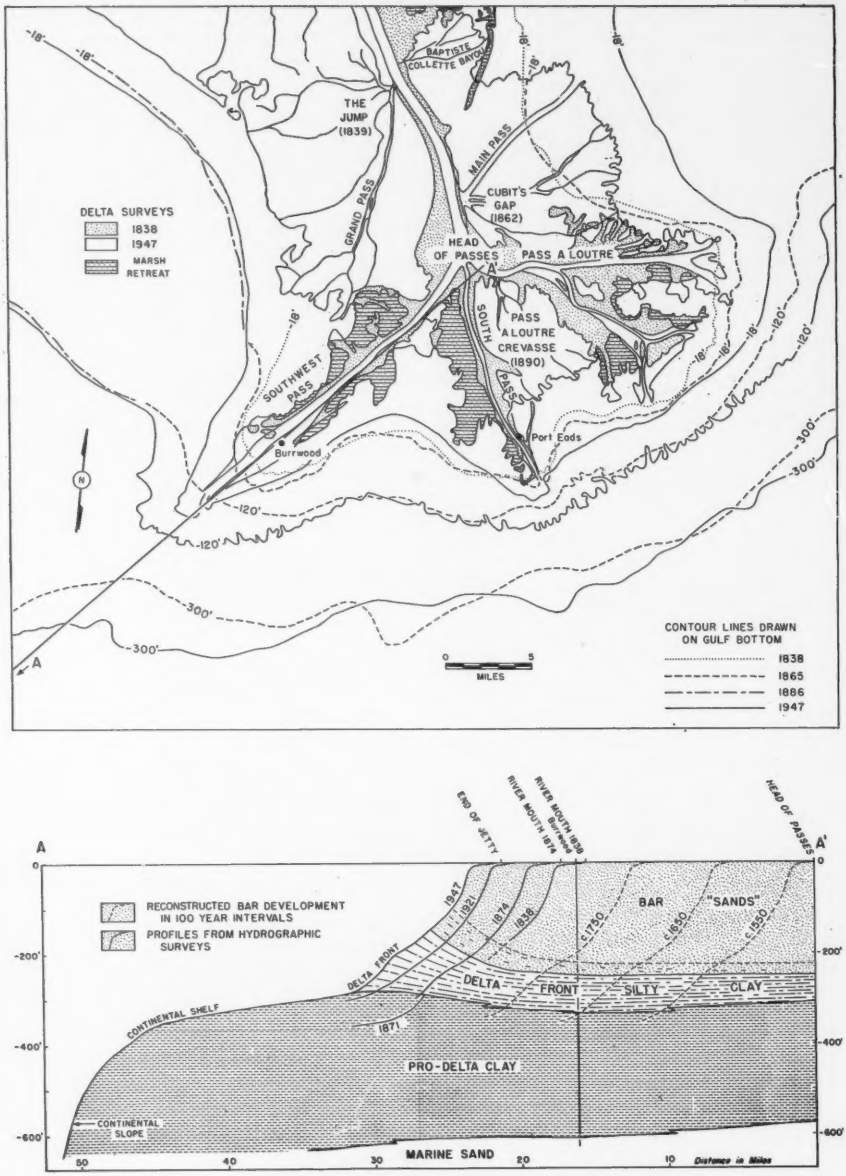

FIG. 15.—Development of the birdfoot delta platform as shown by comparison of data from hydrographic surveys dating from 1838.

delta growth; Pass A Loutre divides into several minor distributaries, and the build-up of the Gulf bottom around South Pass may to some extent reflect sedimentation from the Pass A Loutre crevasse.

The succession of Gulf bottom profiles off the mouth of Southwest Pass taken from hydrographic surveys is drawn on the longitudinal section A-A′ (fig. 15). They show that Southwest Pass has lengthened Gulfward at the rate of approximately 250 feet a year since 1838. At this rate, the Pass began to form at Head Passes approximately 450 years ago. This period of time for pass development may be somewhat short, and the estimated rate of lengthening may be slightly high; after 1908, the jetties restricted the mouth of Southwest Pass, and the resulting localized deposition caused abnormal growth of the bulge along the line of section.

The initial development of Southwest Pass corresponds to the initial stages in birdfoot delta formation and, therefore, the delta is thought to have begun to develop around 1500 A.D. This date is somewhat earlier than the previous estimates of 1600–1700 A.D. made by Fisk (1944, Table 3).

The age of molluscan shells in pro-delta marine deposits as determined from Carbon 14 analysis by Prof. J. Laurence Kulp, Columbia University, coroborates the date assigned to birdfoot delta development. Shells exposed in massive clays of a mudlump, 1 mile east of the mouth of North Pass, proved to be 350 ± 150 years old. The fauna and sediments associated with the molluscs are similar to those found today in the outer zone of pro-delta facies (p. 15), in water more than 300 feet deep. From the age and character of the mudlump deposits, it appears that they were laid down soon after the birdfoot delta began to form. The rate of advance of the delta front off North Pass, as established from the relative position of bottom contours dating from 1838 (fig. 15), indicates that a 300-foot depth of water could not have existed in the area after 1650 A.D. At that time, the delta front would have been located approximately half way between Head of Passes and its present position.

Depth of Water and Delta Growth

The bar fingers provide evidence that the delta platform has advanced into an approximately constant depth of water throughout the period of birdfoot delta growth. The width of the fingers and the slope of their upper surfaces away from the channels are similar to the width and slope of the present distributary mouth bars, indicating deposition under conditions comparable to those existing today. Borings above Head of Passes indicate that, along the main channel, the bar finger is absent, or is much narrower than the fingers of the distributaries. A similar lack of bar finger deposits has been noted along the channels of the abandoned Lafourche-Mississippi delta in Terrebonne Parish, Louisiana (Fisk, 1952, p. 57). These distributaries discharged their load into shallow Gulf waters and lengthened their courses by scouring deep, narrow channels across a previously deposited thick clay topstratum.

Above Head of Passes, near the west bank of the river, borings penetrated non-fossiliferous dark clays, with some organic material, to a depth of more than 200 feet. Farther to the west, near the mouth of Tiger Pass, a 400-foot section of non-fossiliferous clays is present, the upper half of which contains thin sand layers. A number of borings on the east side of the river, south and east of Venice, and north of Pass A Loutre, penetrated 250 feet of non-fossiliferous clay, resting on a 20-to 30-foot sand layer. The sequence of deposits in these upstream areas is in marked contrast to that of the birdfoot delta and must represent older deltaic deposition (fig. 1).

The abrupt change in subsurface sediments near Head of Passes suggests that the birdfoot delta was deposited in deep

water at the edge of an older delta plain. The depth relationships visualized are similar to those now existing at the seaward edge of the St. Bernard-Mississippi delta plain which is bordered by deep water on the outside of the Chandeleur Island arc. In establishing the present main channel above Head of Passes, a distributary of the river scoured its channel across the plain of an older delta and began to drop its sandy load as a bar in the deep water at the plain's edge. A system of distributaries formed at the crest of this bar, and three of them enlarged to become the main passes of the present birdfoot delta.

Sedimentary Volumes in the Delta Framework

By calculating the volume of sediment in the delta platform and the major sedimentary units of the platform, it is possible to estimate the annual load of sediment carried by the river. This computation can be used to check the age of the delta platform, and the estimate of the percentage of material transported by the river as bed load.

The volume of sediments within the outline of the birdfoot delta platform as shown on figure 2, is 27 cubic miles. The rate of sedimentation, based on the estimated 450-year period for delta growth, is .06 cubic miles a year, or 495 million tons.[3] This tonnage is approximately 15 per cent greater than Holle's estimate of 420 million tons a year.[4] Assuming Holle's figure to be correct, it would appear that the time allowed for delta growth is approximately 80 years too short. On this basis, the growth of the birdfoot delta would have started around 1420 A.D.

Holle estimated that 25 per cent of the total river load is bed load. Since the average suspended load consists of 7 per cent sand, 38 per cent silt, and 55 per cent clay, then the addition of 25 per cent of bed load sand would require a revision of total load percentages to approximately 25 per cent sand, 30 per cent silt, and 45 per cent clay. From analyses of bar sand materials, it is assumed that fine and very fine sands make up approximately 60 per cent of the bar fingers. The fingers have a total volume of 5.9 cubic miles; sands, therefore, constitute approximately 3.5 cubic miles, or approximately 13 per cent of the delta platform. The total amount of sand in the delta mass is assumed to be directly proportional to the amount of sand in the river load; if this assumption is correct, Holle's estimate of bed load is excessive. Bed load appears to be more on the order of 7 per cent of the total load, or possibly 10 per cent, if sandy deposits of the interdistributary troughs are taken into consideration.

CONCLUSIONS

The leaf-like mass of the birdfoot delta has developed during the past 450 years. Deposition has proceeded uniformly and has resulted in the seaward elongation of the distributaries from Head of Passes; it has given rise to a pattern of diverging finger-like bar deposits of sands and sandy silts, separated by wedges of silty clay. These sedimentary units, together with an underlying thin layer of prodelta marine clay, form the framework of the delta platform, which has advanced Gulfward into waters approximately 300 feet deep. Subsidence resulting from compaction has accompanied deposition, influencing the rate of delta advance and modifying the shape of the bar fingers. These contemporaneous processes have brought about the burial of the bar fingers that now closely resemble the veins of a leaf.

[3] Tonnage is based on the assumption that the average density of delta sediments is 1.8. Several wet bulk densities of clay and sandy materials from the Burrwood boring gave this average.

[4] Tonnage carried by distributaries below Head of Passes; 500 million tons, less 16 per cent representing the load dispersed through minor distributaries above Head of Passes (Holle, 1952, p. 123).

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FIGS. 1–10, JUNE, 1954

ROUNDNESS AND SHAPE OF MARINE GRAVELS FROM URK (NETHERLANDS), A COMPARISON OF SEVERAL METHODS OF INVESTIGATION[1]

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ABSTRACT

The petrology of gravels from a spit in the lee of the former island of Urk is discussed. The composition shows the gravels to have been derived from glacial till. The relations of roundness to distance of transport and of shape to vertical position on the spit are analyzed. Two principal methods of evaluating roundness and shape, those of Wadell-Krumbein and of Cailleux are compared theoretically and in relation to their results.

INTRODUCTION

The reclamation of the northeastern part of the bottom of the former Zuyderzee has made accessible a large area of predominantly fine grained marine sediments. Only in a few places coarse sands and gravels occur, derived from outcrops of Pleistocene boulder clay. One of these outcrops constitutes the wave-resistant core of the island of Urk. At the northeastern extremity of this island a spit, the so-called "Tail of Urk," has been formed, consisting of sandy gravel, which in this region acquired some economic value as a construction material. The imminent danger of disappearance by exploitation has made it desirable to investigate at least in some respects this deposit, so exceptional in the Netherlands. A detailed morphological study was impossible for lack of time and it was decided to concentrate on an investigation of shape and roundness of the pebbles, with some additional work on composition and grain size. The deposits have disappeared since. The main reason for using this opportunity has been the wish to compare two different methods for the study of roundness and sphericity, the one principally in use in the United States, the other in Europe.

The cooperation of the direction of the North Eastern polder, which made the field work possible and the valuable assistance of Dr. D. J. Doeglas and Dr. R. D. Crommelin are gratefully acknowledged. Very substantial assistance has been given by Dr. H. Scheen in the mathematical evaluation of the relations between Krumbein and Cailleux measures. Of the various parts of this paper the first author assumes main responsibility for the petrological studies, the second for the geology and the third for the determination of the composition of the gravels.

GEOLOGICAL BACKGROUND

The following geological description has been based on studies by De Waard (1946, 1949), Muller and Van Raadshoven (1947), and as yet unpublished work by one of the authors (Wiggers). A geological and sample map is given in figure 1.

The whole area is underlain by Pleistocene glacial deposits, essentially boulder clay of Riss-glacial age (Illinoian) which crops out in the south-west part of Urk and over an extensive area north of the former island.

Incorporated in the Riss-glacial boulder clay lenses of a different till occur.

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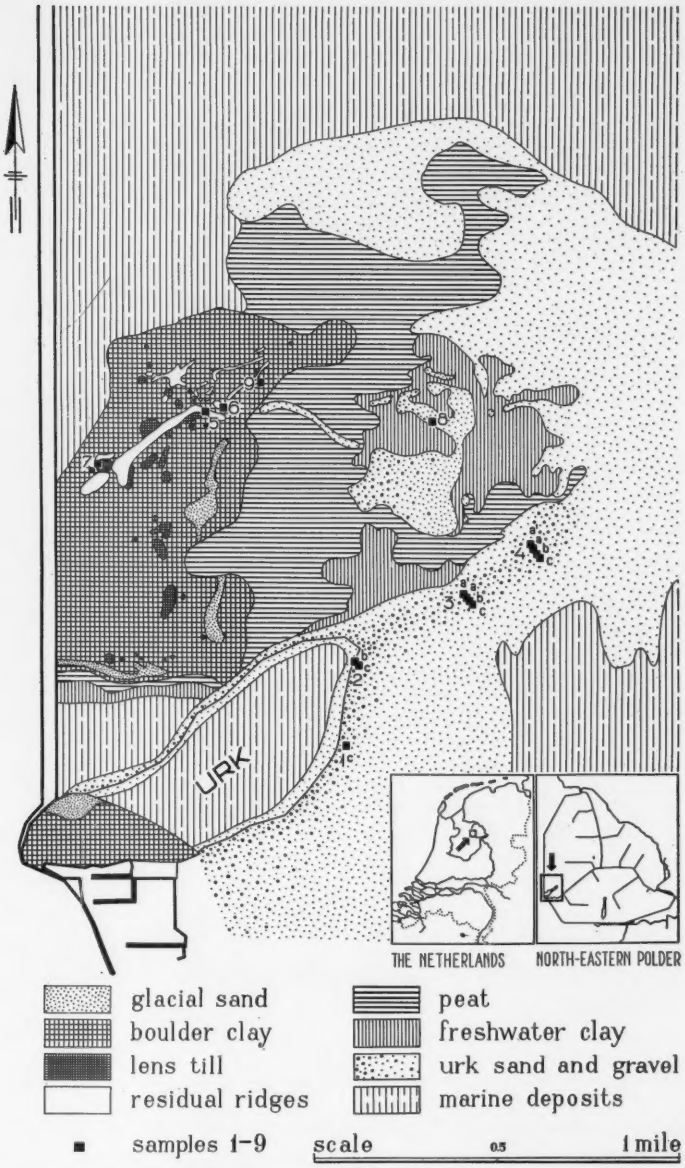

FIG. 1.—Geological and sample map of the region around Urk.

According to De Waard (1949) these lenses have been derived from deposits of an older glaciation, presumably in northwest Germany, and have been carried westward by the ice as kinds of gigantic erratic blocks.

Originally the Pleistocene sediments were partly covered by Holocene peat. About the beginning of this era a layer of fresh water-clay was deposited on this peat. Archeaological observations proved that this clay region, protected by dikes against the rising sea-level, was inhabited in the Middle Ages.

About the beginning of the 13th century the contact between the North Sea and the Zuyderzee became more extensive. A large part of the clay and peat area has been destroyed by erosion. The sea abraded considerably the boulder clay outcrops, which became covered with extensive residual pebble and cobble deposits, rounded and concentrated by the waves.

The finer material was washed out and deposited around the outcrops on the partly eroded peat and clay. The coarse, gravelly sand is called Urk sand. The map shows that the Urk sand has been deposited mainly east of the boulder-clay outcrops.

Farther away marine clayey sediments occur, partly resting upon the Urk sand.

The island of Urk consists of an outcrop of boulder clay and a low clay area. Under the marine clay of the island occurs the freshwater clay, which crops out north of the island. In a shoreward direction the clay changes into sand. The Tail of Urk consists of sandy gravel and represents, as it were, the continuation of these sand ridges. Archaeological data prove that the area around Urk was still inhabited at the end of the 12th century. The first reliable topographical maps, which date from $\pm$1700 A.D. show the the island and the Tail already with their present shape and position. So the Tail of Urk must have been formed between the 12th and 18th century.

The orientation of the Tail (N. 60° E.) does not agree entirely with the prevailing south-southwest winds. It has been shown by Van Veen (1940), however, by means of a study of ancient observations, that during the 18th century, the main direction was slightly more westerly. Hence long-shore drift and accumulation of materials derived from the boulder clay core in the lee of the then prevailing winds may account partly for the formation of the Tail. This does not preclude the possibility of sediment supply from the northern till outcrops by storm floods, or from the entire southern and eastern sand area.

Under the conditions just prior to the reclamation, the south side of the Tail was more exposed to the prevailing wind and wave action than the northern side. Hence the western part (fig. 2, section 3) shows pronounced lateral asymmetry in its profile with the steep slope exposed southeastward. The end of the Tail, however, bends northward and probably reached far enough to come under the influence of the swell that bent around the island and had obtained a more westerly direction. The vertical asymmetry in this part has therefore been reversed (fig. 2, section 4).

At its northeast extremity the wall flattens and broadens and imperceptibly merges into its base. On the island side its morphological development is abnormal as a result of artificial shore protection by groins and stone embankments.

The body of the spit is built up by alternating sandy and pebbly layers, but the surface is constituted by a residual layer of pebbles only. The wide flat platform consists of a very sandy gravel. Apparently wave action at this depth has not been capable of washing out all sand.

A series of samples has been collected along the south shore of the island and on the Tail, and where possible from the platform, the slope and the top. For comparison samples of the boulder clay of the northern outcrops, of the residual ridges on the latter, and of the Urk sand were investigated also.

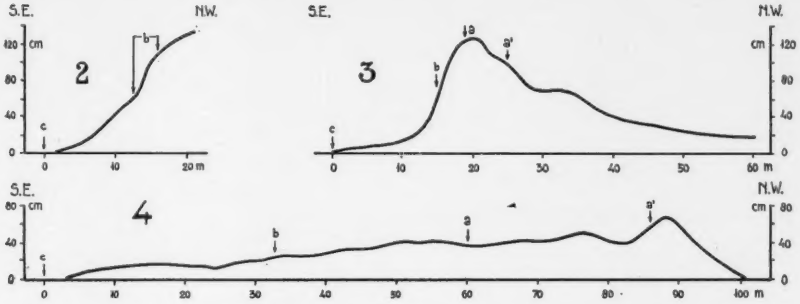

FIG. 2.—Cross sections of the island shore and Tail at the various sample locations. Position of the lowermost sample is zero.

GRAIN SIZE AND COMPOSITION

A study of grain size can be truly significant only when each sample represents a layer deposited under essentially uniform conditions. On the Tail this condition is difficult to fulfill in consequence of considerable artificial disturbance, the very limited thickness of the superficial residual layer and the underlying beds, and the presence of finer-grained interstitial material deposited during the short tranquil phase, when dikes already protected the area. In the short time available it appeared impossible to avoid these sources of errors and only the limited information required for the roundness and shape studies could be obtained by sieving the gravel grade (>4 mm). The artificiality of the lower limit introduces a certain amount of negative skewness in some distributions and produces better sorting. For those distributions only the median retains a certain value. In table I the phi[2] median, phi sorting and phi skewness are given. The latter two have been derived from the 16th and 84th percentile (Inman, 1952). From these data it can be concluded that the samples from the spit wall are generally finer than the corresponding sediments from the platform. The latter show a linear increase of size in phi with increasing distance from the boulder clay core of the island (fig. 3). This fact seems to disagree with other evidence, which points to this core as a major source of the Tail sediments (see below). Progressively greater exposure to wave action with increasing distance from the protection offered by the island may explain this phenomenon.

The other samples, which occupy very different positions in relation to the relief and show a strong influence of the deficiencies of the method, do not permit any general conclusions.

The Pleistocene boulder clay forms the only possible source of the Tail gravels. As concerns petrographic composition this source is not homogeneous. De Waard (1949) has shown that incorporated in the dark normal till numerous large lenses or blocks of a very different till occur. According to De Waard these lenses have been derived from the deposits of an older glaciation, presumably in northwest Germany, and have been carried westward by the ice as kinds of gigantic erratic blocks. The petrographic composition of their gravels is very different from that of the normal boulder clay and since they contain many more pebbles per unit of till (±3–5 times as many) the composition of the outwash

[2] Diameters in phi are the negative logarithms to the base of 2 of the diameters in mm. as proposed by Krumbein.

TABLE I.—*Parameters of grain size distributions of Tail gravels*

Sample number	1c	2b	2c	3a′	3a	3b	3c	4a′	4a	4b	4c
Md ϕ	3.45	2.85	3.75	3.55	3.50	3.50	4.20	2.65	3.30	3.00	4.30
Sorting $=\sigma\phi$	1.30	0.50	1.30	1.00	0.65	1.20	1.20	0.55	0.80	0.60	1.70
Skewness $=\alpha\phi$	−0.06	−0.06	−0.42	−0.12	−0.24	−0.50	−0.35	−0.51	0.0	0.18	−0.11

gravels is largely controlled by the presence of lenses of till in the source area. Table II contains the petrographic analyses of some of the samples (analyses by Maarleveld).

From this table and analyses of De Waard (1949) the principal difference between lens till and normal till appears to be the absence of flint in the former. Moreover, the limestone percentage, though variable, is much lower in the normal till.

The percentages of the principal components flint, crystalline rocks and limestone have been recomputed to 100 and plotted in fig. 4 (20–30 mm grade). All mixtures between normal till and lens till would plot in the cross-hatched area. The Urk sand sample represents such a mixture in which normal till predominates. It is apparent that the composition of the samples from the residual ridges does not result from mixing only. Such a composition has to be explained by selective removal (by abrasion) of the limestone, resulting in high percentages of crystalline rocks. Since they contain but little flint and flint under the existing conditions is very resistant, the original material must have contained a large amount of lens till material.

The position of the Tail samples can be explained in two ways. The first possibility is progressive mixing of residual ridge type material and a fresh gravel in which lens till predominates. The amount of residual ridge material required would not exceed 40 per cent. Another explanation is selective removal by abrasion of limestone from a limestone-rich source material without admixture of residual gravel. The line B represents such a theoretical development by removal of limestone from a lens till gravel with ±20 per cent or normal till. Petrographic considerations alone are insufficient to solve this problem, especially since the data are scarce.

Similar relations could be shown for the 5–8 mm grade. The relative increase of limestone in this grade, which accompanies the decrease in the 20–30 mm grade, points to selective abrasion as a major cause for the variations in composition of the Tail gravels. The combined data from both fractions are therefore in favor of a derivation from lens till and modification by abrasion, that is a derivation from the boulder clay core of the the island itself and not from the Urk sand, if the single sample of this latter would be representative of the whole. As

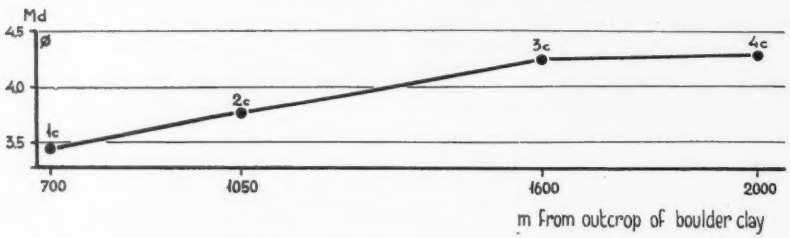

FIG. 3.—Relation of median size in phi to distance from the boulder clay core of the island for platform samples (c-series).

TABLE II.—*Petrographic composition of samples from the Tail and from source formations*[1]

Number		Flint		Crystalline		Limestone		Quartz		Others	
	Size Grade in mm	20–30	5–8	20–30	5–8	20–30	5–8	20–30	5–8	20–30	5–8
1c	Tail	12	5	32	41	29	28	—	5	27	21
2c	Tail	14	8	27	36	30	29	2	4	27	23
3c	Tail	20	8	32	47	24	23	—	2	24	20
4c	Tail	19	6	32	41	18	32	2	4	29	17
5	Residual Ridge	7	5	50	44	16	26	3	6	24	19
6	Residual Ridge	16	4	42	44	1	23	4	8	37	21
7	Lens till	1	—	26	26	63	70	—	—	9	4
8	Urk sand	32	21	26	37	5	2	2	6	35	34
9	Norma till	38	14	23	44	1	1	2	9	36	32

[1] Figures given in percent by number of pebbles in a given size grade.

it is, this argument has to be used with considerable care.

METHODS OF STUDY OF SHAPE AND ROUNDNESS

Wadell (1932) was the first to show that there is a fundamental difference between shape and roundness and that these properties are geometrically independent. An object may be quite spherical in shape but completely angular, for example a dodecahedron; or perfectly rounded but far from spherical, for example a cylinder capped by two half spheres. The shape of particles influences their behavior during transport and deposition, since spherical particles settle more quickly from a suspension and roll faster in bottom transport than flat particles. Hence sorting may be controlled partly by shape. Roundness is influenced by rigor of wear and distance of transport, but does not have any effect on sorting or transport. The definitions of roundness and sphericity are entirely independent and it is generally assumed that only very great changes in one may influence the other (Pettijohn, 1949, p. 54). This independency of definitions is an important prerequisite for the study of both properties.

Based on the assumption that particle shapes can be arranged in a series with the sphere as the most developed stage, Wadell has expressed shape as the ratio between the surface of the particle and the surface of a sphere with the same volume. Krumbein (1941a) has shown that this ratio, the sphericity (S) of the grain which ranges from 0 to 1 for perfect sphericity, can be simplified with satisfactory accuracy to one in which only the longest (a), the intermediate (b) and the shortest (c) diameters of the particle appear, that is $S = \sqrt[3]{bc/a^2}$. His definition of these diameters has been followed in the present study. The computation of the ratios b/a and c/b permits the graphical determination of the sphericity. Figure 5 shows the plotting in a sphericity graph of all pebbles of sample 1 c.

So far it has been tacitly assumed that shape and sphericity are identical notions. Figure 5 shows, however, that, for instance, disc-shaped and rod-like particles may have the same sphericity, notwithstanding the fact that they have very different shapes, and presumably will behave in different ways during transport and deposition (Krumbein, 1941a). Hence the use of sphericity values in sediment studies does not always permit the complete evaluation of shape influence. This difficulty can be overcome by using sphericity diagram plots instead of actual sphericity values, whereas large numbers of samples may be summarized by classing the pebbles into 4 classes, each indicating a part of the field of the sphericity diagram. These classes have been used first by Zingg (1935) and the Zingg percentages constitute a useful

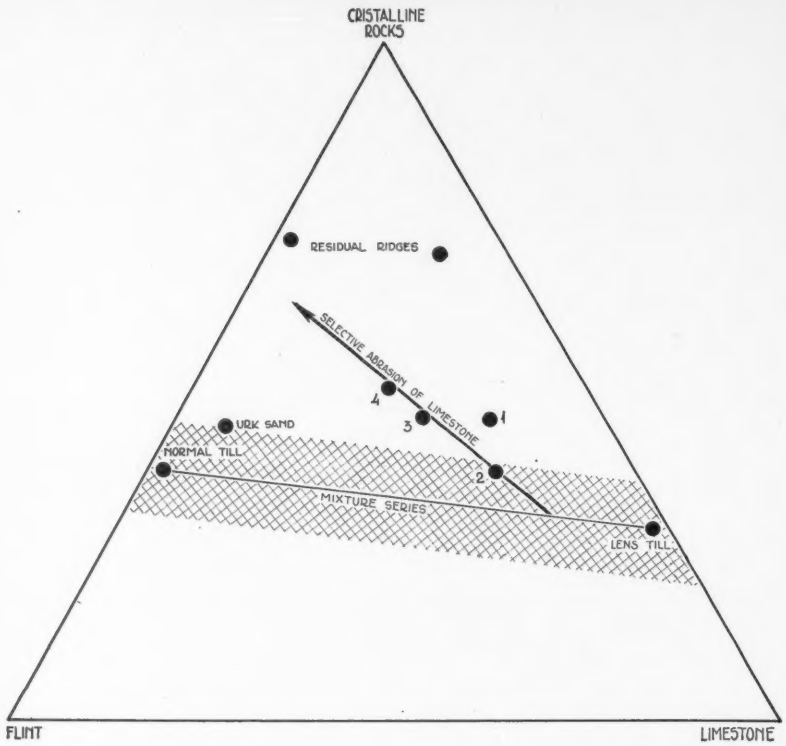

FIG. 4.—Triangular diagram of the petrographic composition of tail and potential source samples, 20–30 mm grade.

supplement to the sphericity values.

Roundness (*Rw*) was expressed by Wadell as the ratio between the radius *r* of the sharpest corner of the particle and the radius *R* of the largest inscribed circle, both in the maximum projection of the particle. The measurement of roundness in this way is lengthy and Krumbein (1941a) has constructed a chart for visual determination of roundness (*Rk*) by comparison with pebbly images, the roundness of which has been measured by Wadell's method. The agreement between determinations in both ways is close, when large numbers of pebbles are used (25 or more). The values range from 0–1, the latter representing perfect roundness, whatever the shape may be.

Many more methods for the determination of shape and roundness have been proposed. The majority have not found wide usage, except those of Cailleux (1945, 1948), which have provided the data for a considerable series of investigations by French and German students (for example Berthois, 1950, 1951; Cailleux, 1945, 1947, 1948; Hövermann and Poser, 1951; Pouquet, 1950; Tricart, 1951; Tricart and Schaeffer, 1950, and

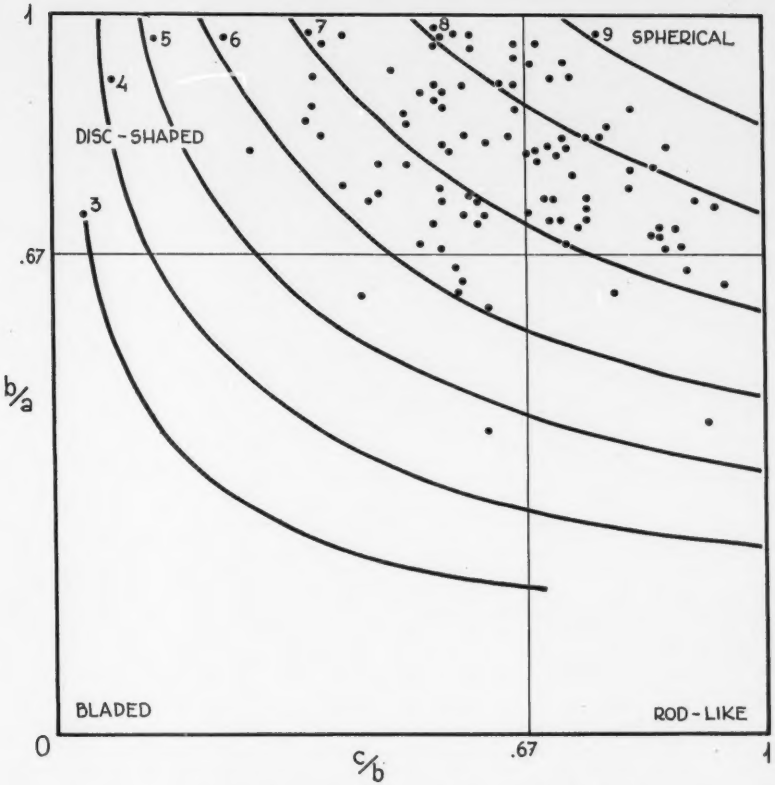

FIG. 5.—Sphericity diagram of all pebbles of sample 1 c.

others). It is therefore desirable to examine the theoretical relationships between both sets of measures. The results obtained by both will be compared in the next section.

Cailleux's shape factor is the flatness index $F=a+b/2c$, as originally proposed and used by Wentworth (1922). The definition of the intercepts a, b and c is the same as for Krumbein's sphericity S.

In figure 6 the relations between S and F has been given for all Urk samples. All available F measurements of individual pebbles have been classified acccording to their S-class (class-interval of 0.1). The arithmetic mean and standard deviation of the F distribution in each S-class have been plotted against the mid-point of the S-class. This method is not entirely correct but considered to give a fair approximation.

The theoretical relation between $F=(a+b/2c$ and $S=(bc/^2)^{\frac{1}{3}}$ depends on the distributions of a/b, b/c and c/a. Uniform or patchy distributions of each of these ratios and their mutual relationship result in a different relationship between S and F. The mathematical treat-

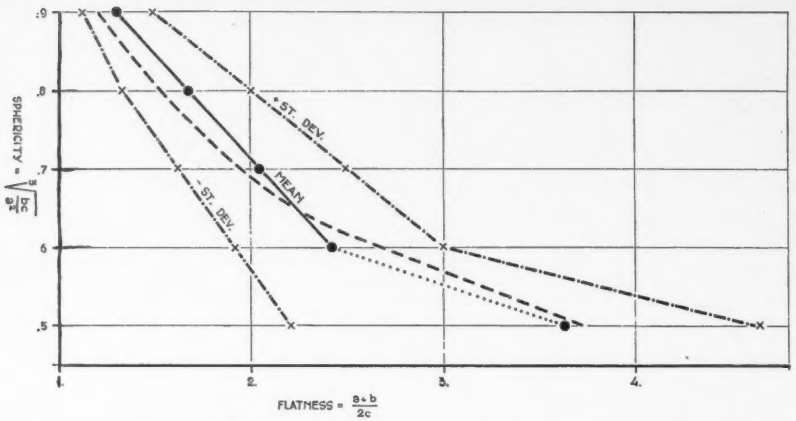

FIG. 6.—Relation between sphericity (S) and arithmetic mean and standard deviation of flatness (F) per class of S for all Urk samples. Broken line: theoretical relationship of F and S assuming uniform distribution of b/a and c/b (see text).

ment of these various possibilities, which has kindly been undertaken by Dr. H. Scheen, will not be discussed here. However, if we assume uniform distribution of b/a and c/b, visualized by points distributed evenly over a diagram like that of figure 5, we find a relationship between S and F as represented by the broken line in figure 6, which quite closely agrees with the experimental relations. If the points occur mainly in the upper left hand or lower right hand corner of figure 5 the line of theoretical relation shifts to the position of one of the standard deviation curves. From this we may draw the conclusion that the combined usage of S and F would supply information of the same type as do the Zingg-percentages. The flatness ratio itself does not distinguish between roller-shaped and disc-shaped pebbles, since it compares c to the average of a and b. Thus it does not offer a means of avoiding the deficiencies of S.

Roundness (Rc) has been defined by Cailleux (1947) as the ratio of the diameter of the sharpest corner ($2r$) in the plane of maximum projection and the greatest length a. It bears a certain resemblance to the Wadell-Krumbein definition of roundness, which as a first approximation may be written as $Rk = 2r/b$. In both cases the maximum value of $2r = b$ and it is obvious that only when the largest projection of the particle is a circle can Rc reach its maximum value of 1. A cylinder capped by two spheres is perfectly rounded, $2r = b$ and $Rk = 1$, but Rc may have one of an infinite series of values, depending on the ratio b/a. As a mathematical conception Rc, partly controlled by shape, is definitely inferior to Rk.

If we assume the largest projection to be an ellipse then $2r = b^2/a$, $Rk = 2r/b = b/a$ and $Rc = 2r/a = b^2/a$. The relation between Rc and Rk is thus the function $2r/a = (2r^2/b)$ or $Rc = (Rk)^2$. When the largest projection is not an ellipse Rk will always be higher for the same value of Rc, than the value given by the equation. The Rc values of all pebbles of Urk have been classified according to their Rk classes. The arithmetic mean and standard deviation of the Rc distribution in each Rk class have been plotted in figure 7 against the mid-

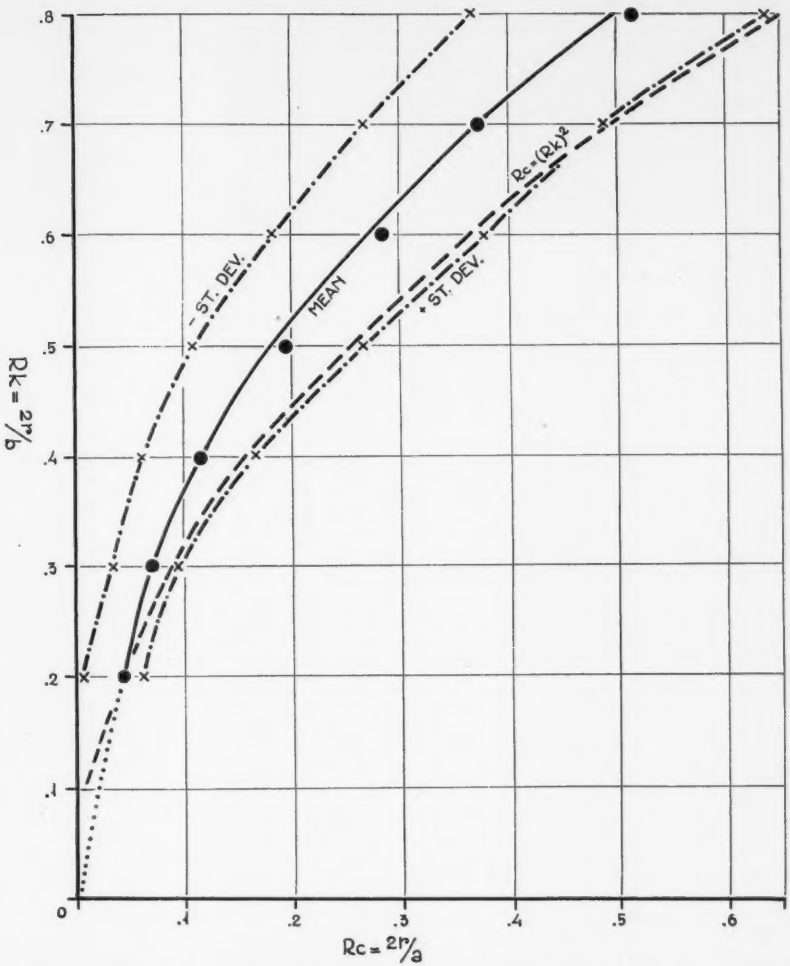

FIG. 7.—Relation between Krumbein roundness (*Rk*) and arithmetic mean and standard deviation of Cailleux roundness (*Rc*) in each class of *Rk* for all Urk samples. Broken line: theoretical relationship, when the largest projection is an ellipse.

point of the latter. The curve for the positive deviation closely agrees with the theoretical relation for an elliptical projection. The majority of the pebbles, however, apparently have projections that are not ellipses and their *Rk* values are higher than expected from theoretical considerations.

TABLE III.—*Correlation between size and shape and size and roundness in the 20–40 mm grade of Urk samples*

Sample number	*n*	Shape—Size		Roundness—Size	
		r	*P*	*r*	*P*
1c	100	0.17	>0.10	0.18	0.10
3a	100	0.13	>0.10	0.18	0.10
3c	100	0.16	>0.10	0.09	>0.10
7	100	0.11	>0.10	0.11	>0.10

The determination of $2r$ for *Rc* is carried out by selecting visually the sharpest corner and determining its diameter on a disc with concentric circles to the nearest 0.5 mm. With decreasing size and rounding the accuracy of this technique also decreases rapidly (Berthois, 1952).

The numerous studies mentioned before demonstrate that in spite of their deficiencies *Rc* and *F* are valuable tools especially in environmental studies. It is beyond doubt, however, that a large scale application of *Rk*, *S* and Zingg percentage would yield the same results. The determination of *S* is slightly more time-consuming than that of *F*, but this is counter-balanced by the more rapid and accurate determination of *Rk* as compared to that of *Rc*. Personal experience and published data (Krumbein, 1941a) show, that the accuracy of all measurements, even when carried out by different persons, is very satisfactory.

A definite relation exists between roundness or sphericity and size. Since separate determinations in all size grades would be too time-consuming, only the 20–40 mm grade has been studied. Within the limits of this grade there is no significant relation betweeen size and shape or roundness. Correlation coefficients (r) for size/roundness and size/sphericity within the chosen grade have been calculated for a set of representative samples, using b as a size measure. The correlation is virtually non-existent in all cases, since r is low and P, indicating the probability that the relation is due to chance only, is high.

Since the rock type is of considerable influence on the effects of abrasion and on shape, petrographic homogeneity of the material is necessary. In this study limestone has been selected for its abundance, easy recognisability, comparative susceptibility to wear and rather uniform hardness. Samples 1c, 3a, 3c, and 7 have been measured for one hundred randomly picked pebbles (table III).

SHAPE AND ROUNDNESS OF THE URK GRAVELS

The roundness and shape frequency distributions of each sample can be summarized in conventional statistics, that is in terms of a normal probability distribution and deviations thereof. Usually the median and quartile parameters are used, but for the present study it was thought that statistics describing not only the central part of the distribution but also its extreme ends would be most relevant. Hence the first three moments about the mean have been calculated and the arithmetic mean, standard deviation, and skewness of the frequency distributions of *Rk*, *Rc*, *S* and *F* have been tabulated in table IV together with the Zingg percentages.

The data for *Rk* and *Rc* have been represented in figure 8. Assuming as a working hypothesis that distance of transport is one controlling factor for roundness, the means of the *c*-series of Tail samples have been plotted against the distance from the island, a potential gravel source. The samples of lens till (no. 7), residual ridges (no. 5) and Urk sand, presumably in the given order, also

TABLE IV.—*Arithmetic mean, standard deviation and skewness of the frequency distributions of roundness (Rc−Rk) and shape (S−F) and Zingg values of all Urk samples*

Sample number	1c	2b	2c	3a	3b	3c	4a	4c	5	7	8
Rk = Krumbein roundness											
Arithm. Mean $\bar{X}$	.494	.500	.499	.549	.537	.533	.553	.575	.422	.305	.478
Std. Error of $\bar{X}$	.008	.010	.007	.009	.008	.007	.009	.008	.010	.013	.010
Std. Dev. σ	.085	.096	.071	.086	.080	.075	.089	.082	.102	.133	.105
Skewness α	+.040	+.045	+.040	+.055	+.049	+.056	+.047	+.032	+.057	+.076	+.093
Rc = Cailleux roundness											
Arithm. Mean $\bar{X}$	.234	.282	.259	.267	.298	.309	.289	.333	.156	.085	.194
Std. Error of $\bar{X}$	.010	.014	.009	.010	.012	.012	.013	.011	.010	.006	.013
Std. Dev. σ	.104	.139	.095	.106	.117	.123	.127	.114	.102	.059	.102
Skewness α	+.074	+.109	+.044	+.042	+.076	+.095	+.118	+.018	+.110	+.112	+.099
S = Sphericity											
Arithm. Mean $\bar{X}$	.698	.678	.695	.699	.729	.747	.720	.702	.711	.690	.685
Std. Error of $\bar{X}$	.007	.010	.007	.007	.008	.008	.009	.008	.007	.008	.008
Std. Dev. σ	.070	.104	.074	.075	.083	.079	.088	.076	.073	.084	.076
Skewness α	+.228	+.048	+.111	+.148	+.408	+.744	+.627	+.403	+.053	+.059	+.381
F = Flatness ratio											
Arithm. Mean $\bar{X}$	1.75	2.45	1.81	2.02	1.86	1.75	2.00	1.86	1.75	1.96	1.93
Std. Error of $\bar{X}$	0.05	0.10	0.05	0.06	0.07	0.04	0.07	0.05	0.04	0.05	0.05
Std. Dev. σ	0.49	0.96	0.54	0.57	0.68	0.42	0.66	0.47	0.39	0.50	0.47
Skewness α	+0.52	+1.03	+0.56	+0.61	+0.83	+0.43	+0.74	+0.48	+0.49	+0.39	+0.40
Zingg shape percentages											
Bladed	6	14	6	12	9	3	10	5	4	5	10
Rod-like	14	13	12	12	15	13	15	10	16	26	15
Disc shaped	38	64	48	54	42	44	44	45	42	50	50
Spherical	42	9	34	22	34	40	31	40	38	19	25

represent a series of progressive wear, but the distances of transport corresponding to each stage are unknown and even low and irrelevant in the case of wave-rounding in the residual ridges. In the left hand part of figure 8 these samples are therefore spaced equally and the steep rise of the curve connecting their mean roundnesses does not represent an especially rapid increase. Only the *c*-series has been represented, since only these samples were taken in comparable places. Only such samples can be compared directly, since it is conceivable that a lower or higher position on the gravel wall may appreciably affect roundness. On this point the available information is somewhat contradictory. We shall first confine the discussion to the *Rk* data.

The increase of roundness with increasing distance from the island points again to the boulder clay of Urk as the principal source and confirms the reasoning based on the composition of the gravel. If we assume the gravel of the boulder clay of Urk to have the same mean roundness as the pebbles of sample no. 7, we may tentatively reconstruct the complete roundness-distance graph (fig. 9) The shape of this curve is quite remarkable. After a steep rise the curve levels off markedly after about 1500 m. In general shape this part of the curve is quite similar to abrasion mill graphs published by Krumbein (1941b) but for the distance, which is only about half the distance of travel in the abrasion mill. We may see here the influence of the waves on this somewhat exposed shore, washing the pebbles back and forth and causing the actual distance of travel to be much greater than the distance measured in a straight line from the point of departure.

After this subhorizontal part the curve

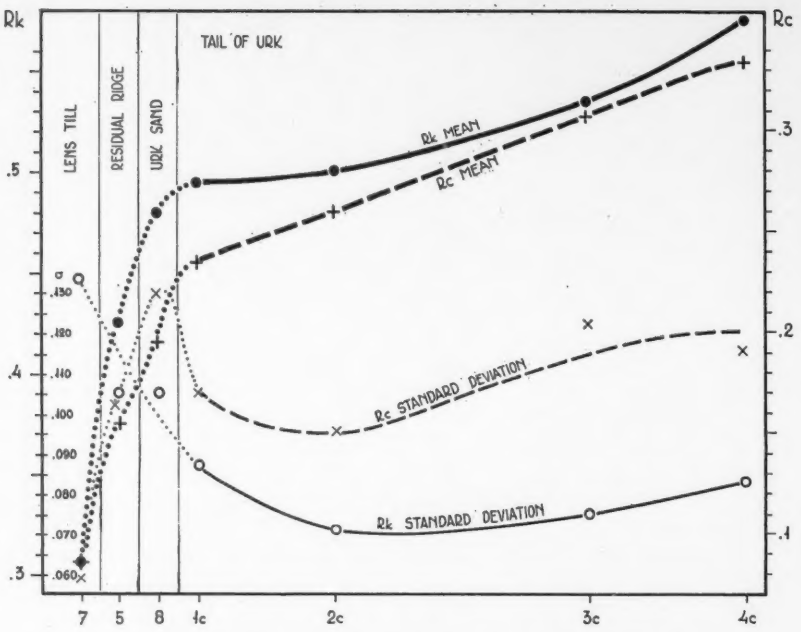

FIG. 8.—Variations of mean roundness (*Rk* and *Rc*) along the Tail of Urk (horizontal axis indicates field spacing of samples) and among possible source gravels (spacing unrelated to transport distances).

surprisingly starts to rise again about halfway down the Tail. This behavior recalls the unexpected increase of grain size with increasing distance from the island as described before. Probably the explanation is the same and has to be sought in an increase of wave energy where the protection offered by the island gradually disappears. Thus the pebbles enter a second cycle of rounding after their first adaptation to the moderate vigor of transport along the island shore.

The trend of the rounding curve at the same time seems to exclude the possibility of a fresh supply of gravel, for instance from the Urk sand from the north, since such a supply of relatively low roundness would considerably affect the smooth rise of the curve. The possibility remains, however, that the Tail has originated as a result of concentration by waves of a local patch of Urk sand sufficiently long ago to reach a stage of roundness equilibrium. The roundness curve in that case would only reflect the adaptation at each point to local wave activity and not the relation between rounding and transport. The petrographic composition is not a very reliable argument against this hypothesis, since Urk type sand deposits so near the island may well have had a composition more similar to that of lens till than sample no. 8. On the other hand a progressive increase of wave energy, sufficient to explain the first steep increase of roundness, seems hardly probable along the island beach. Moreover longshore transport cannot be

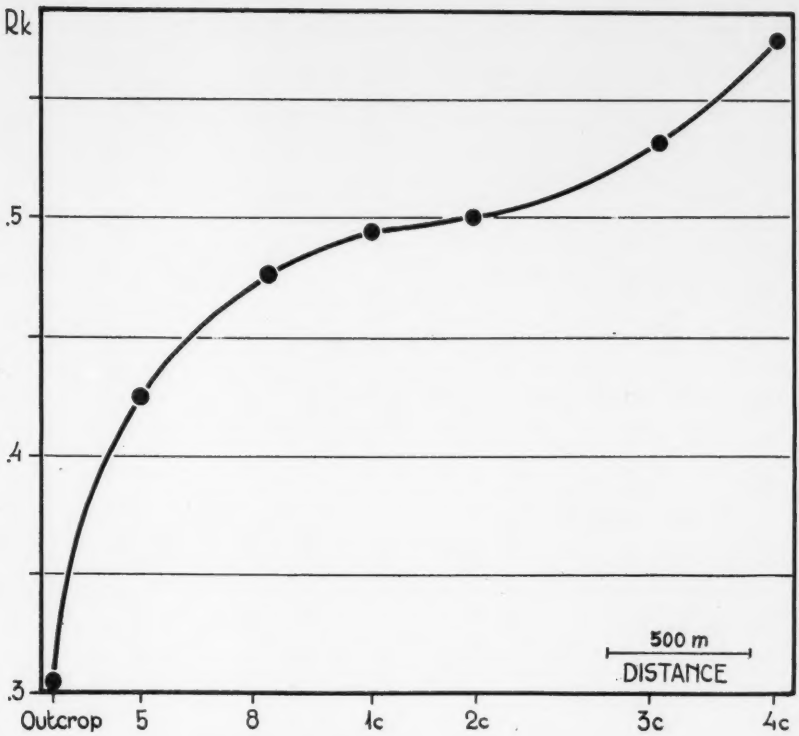

FIG. 9.—Reconstructed relation between mean roundness and distance of transport on Urk.

ruled out with wind directions from the south-southwest. A composite origin seems therefore probable. An argument in favor of such a composite origin is the relative scarceness of gravel between the island core and point 2. We may therefore tentatively explain the Tail as a wave concentrate of an Urk sand type deposit, which itself originally has been derived from till. Some supply of gravel directly from the island must have been going on. Recent supply of Urk sand from the north or northwest seems improbable.

The standard deviation of the roundness frequency distributions shows a marked tendency to decrease with increasing mean roundness until the first equilibrium stage is reached. Apparently all pebbles tend to reach the same roundness which is the mean roundness of the equilibrium stage. The onset of a new cycle of rounding interrupts this development and is accompanied by a slight increase of the standard deviation possibly as a result of chipping and even initial breakage. In the light of the theory on the origin of the Tail as given above this means that no perfect adaptation to local wave energy and no complete stability have as yet been reached.

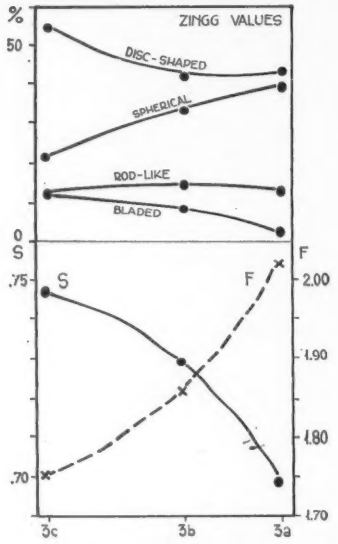

FIG. 10.—Changes in shape in a section across the Tail at location 3.

Thus longshore transport may still be important. The asymmetry as expressed in the skewness of the distributions is small and positive. The latter indicates that everywhere an appreciable number of pebbles are considerably less rounded than the majority, but that nowhere have any been rounded much better. This again points to the existence of a roundness maximum for each local set of conditions. Frost action and glacial transport easily account for the very high skewness in the source material (no. 7). In this case of no. 8, an explanation is not easily given but may be sought in the fact that this is the only deposit in which sand predominates.

The *Rc* data show the same general increase, but with less detail (figure 8). It would be possible to trace and explain all deviations from the *Rk*-curve by means of a detailed analysis of the *a*/*b* relations. The second rounding cycle for instance is entirely obscured by the much higher rate of increase of high *Rc* as compared to high *Rk* values (compare fig. 7). Since each of the lower *Rc* classes comprises a much wider range of roundness values than do the lower *Rk* classes, a relation which gradually reverses with increasing roundness, the *Rc* standard deviation begins low, increases to a maximum and decreases again.

Inspection of the shape data of table IV shows that no significant variations in *S*, *F* or Zingg values are discernable along the Tail. The variation is small and hardly exceeds the standard error of estimate of the mean. If there is a tendency of special shapes to be transported more rapidly, the effect is entirely obscured by the inaccuracies of sampling and analysis.

A profile across the wall, on the other hand, shows a marked regularity. The changes in section 3 are presented in figure 10. The other sections are incomplete and the positions of the samples, as appears from figure 2, are not comparable. The marked decrease of sphericity and increase of flatness towards the top of the wall is explained by the concentration of spherical particles on the platform and bladed and disc-shaped pebbles high on the slope (Zingg values). The rod-like pebbles show no special preference. Since spherical particles are more susceptible to traction and flat particles are more susceptible to suspension transport (Wadell, 1934, Krumbein, 1942), it seems that suspension transport is the main agent in wave sorting. Possibly this active lateral sorting process is partly responsible for the lack of longshore shape sorting.

The *S* and *F* frequency distributions show no significant variations in standard deviation and their skewnesses vary largely and erratically.

Cailleux (1945, 1947, 1948) and Tricart and Schaeffer (1950) give typical values for *F* and *Rc* in various environments. Their values for glacial and marine pebbles have been tabulated below (table V) for comparison with the Urk samples. The general agreement is quite satisfactory. Unfortunately insufficient

TABLE V.—*Typical roundness and shape values of morainic and beach pebbles compared to Urk data*

	Morainic Gravel		Beach Gravel	
	RC	*F*	*Rc*	*F*
Cailleux 1948	—	—	0.32 –0.51	2.3 –3.4
Cailleux 1947	—	1.7	—	2.0 –3.0
Cailleux 1945	—	—	0.250–0.610	—
Tricart & Schaeffer	0.100–0.150	—	0.300–0.350	—
Urk	+0.100	1.75	0.200–0.330	1.75–2.50

Rk and *S* data are available to permit a similar comparison.

SUMMARY AND CONCLUSIONS

The results of this study may be summarized as follows:

A. Concerning methods of investigation.

1. Krumbein (*Rk*) and Cailleux roundness (*Rc*) are closely related. Determination of *Rc* is more precise at least for higher classes than determination of *Rk*, but also more time-consuming.
2. *Rk* data seem to provide more detailed and more pertinent information than *Rc* data.
3. Sphericity (*S*) and flatness (*F*) are shape factors of the same type and both provide incomplete information only. Determination of *S* is more lengthy but provides Zingg shape values at the same time. The latter constitute a necessary additional source of information.
4. *Rk*, *S* and Zingg data together constitute a set of measures which are as practicable as and more relevant than *Rc* and *F*.

B. Concerning the Urk gravels.

5. Petrographic and roundness data point to lens till in the island as a source of the Tail gravel. Probably, however, a patch of Urk type sand material has partly supplied the material. Longshore transport probably played a minor but significant part.
6. Roundness and grain size increase with increasing distance from the island, probably in consequence of progressive disappearance of the protection offered by the island.
7. The roundness at each point of the Tail is largely in equilibrium with local wave energy.
8. Shape sorting is a factor in the distribution across but not along the Tail.

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PLATE 1, TEXT FIGS. 1–3, JUNE, 1954

A NEW TEACHING AND RESEARCH AID IN SEDIMENTATION

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ABSTRACT

A new microprojector has been adapted for use in visually demonstrating samples of various types of sediments in classroom and laboratory. Also, replica techniques have been developed for projection study of various types of voids in carbonate rocks. Methods of preparation of the various types of micro-projection images are described, as well as techniques for reproducing the images in permanent form.

INTRODUCTION

The purpose of this paper is to describe briefly and to illustrate the use of a new microprojector which has been adapted to both teaching and research work in the field of sedimentation. It is often difficult for the instructor in any subject involving microscopy to discuss and illustrate a particular field of interest beneath the microscope to several persons at the same time, particularly when using the stereoscopic binocular microscope with reflected light. The use of the special microprojector and techniques described herein has been of great value to the writer in demonstrating to class groups many significant parameters of sediments and sedimentary rocks, including particle size, shape, and roundness, petrofabrics, and the nature of voids in carbonate rocks. In addition, the writer has found the techniques herein described to be of great value in expediting the measurement of roundness, sphericity, and porosity of large numbers of samples in sedimentological research, since, in many cases, the use of replicas and strews of sediments in microprojection eliminates the tedious and time consuming preparation of thin-sections.

THE PROJECTION SYSTEM

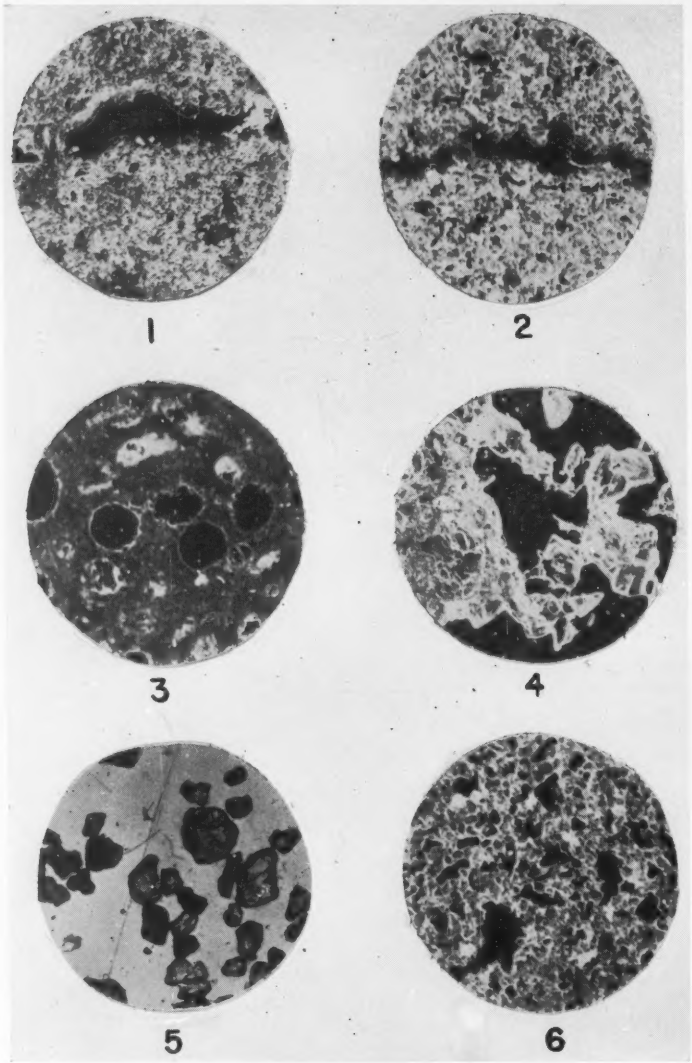
The microprojector used is one manufactured by the Brush Development Company under the trade name of the "Faxfilm Projector." Kits for preparation of the "Faxfilms," or acetate replicas, are also available. The system was developed for preparation and projection of acetate replicas of various types of surfaces, and is widely used in metallurgical and engineering research, ceramic engineering, and in studying the effects of abrasives and cutting tools on various surfaces.

The projection lens is an f:2.46 coated lens, which furnishes a convenient magnification of 1 diameter per inch of projection distance (measured from lens to screen. Illumination is furnished by a standard 100-watt projection lamp, focussed on to the small area of the object mount by a planoconvex parabolic condensing lens.

Microprojection of acetate replicas of surfaces is based on the fact that, when the smooth surface of the acetate film is indented by any slight protuberance, the indented area becomes less transparent to light, and appears darker on the projected image than the areas of film untouched by irregularities on the surface being duplicated. Very minute textural changes as reflected on the micro-relief of the surface are faithfully reproduced in reverse when the thin strip of acetate film, moistened and softened by application of a solvent, is pressed against a surface and allowed to dry and harden. When peeled off the specimen and projected onto a screen, a type of "three-dimensional" image results.

ACETATE REPLICAS OF ROCK SURFACES

Many types of sedimentary rocks lend themselves readily to surface texture study by the replica or "peel" technique.



EXPLANATION OF PLATE 1

Note: All photographs are ×30 unless otherwise specified, and with the exception of figure 5, are produced by projection of acetate films directly onto enlarging paper. All voids therefore appear black. Figure 5 is a print made from a photographic negative, onto which the strew was projected. Fig. 1.—Crevice-type void in Arbuckle dolomite, western Kansas, slightly enlarged

The method of preparation of the specimens is quite simple: the surface to be studied is cleaned with very dilute hydrochloric acid, and a strip of acetate film, moistened and softened by a solvent applied to one side, is pressed onto the rock surface and held under pressure for a few minutes until the drying and hardening of the moistened surface is completed.

Care should be taken to insure a full contact between the film and the rock surface, and to avoid the formation of air bubbles. Pressing down with the flat end of a small rubber cork will help insure a firm, full contact.

If the rock surface is undulating or somewhat uneven, it has been found helpful to use a small ball of modeling clay or plasticene for pressing the acetate strip on to the rock surface. This technique is applicable to the preparation of replicas of shale and sandstone surfaces, and in particular when the surfaces are marked with ripple marks, swash line marks, and similar structures.

After the "Faxfilm" strip has dried, it is then carefully peeled from the rock surface and mounted in one of the 2-inch square cardboard slide mounts furnished with the replica preparation kit. These slides are folded double, with the inner surfaces gummed, and are provided with a half-inch circular hole in the center, across which the replica film is stretched. When the film has been placed across the aperture, the moistened inner surfaces of the slide are pressed together firmly, and the replica is ready for projection.

When replica studies are to be made of such rock types as limestones, dolomites, etc., the samples are first sawed in the desired orientation, ground to a flat surface using a medium to fine abrasive, and lightly etched with dilute hydrochloric acid, and the replicas are prepared as described above.

In projection of such acetate replicas as those of porous limestones and dolomites, the pore spaces will appear as clear transparent areas, where the surface of the film has not been roughend by contact with the rock surface. Intercrystalline and fracture-induced voids are easily recognized, as well as oolocastic porosity. (See pl. 1, figs. 1–4.) Cleavage planes and crystal outlines, as well as microfossils often appear quite distinctly on the projected replica image. Replicas of porous sandstones may also be satisfactorily prepared as shown in plate 1, figure 6.

If limestone surfaces are being studied by the progressive etching technique described by Lamar (1950), the acetate replica method could be employed to advantage in recording the etched limestone surface at various stages of the process. Progressive studies could also be made of the enlargement of voids by acid solutions, and replicas of each stage recorded for detailed study.

Larger surfaces may be studied by using cellulose acetate in thin sheets up to $3\frac{1}{4}''$ by $4\frac{1}{4}''$ and projecting the replicas with a standard lantern slide projector. Strips of the cellulose acetate ribbon furnished with the "Faxfilm" kits may also be used, and bound between ordinary glass microscope slides, using cellulose tape.

PREPARATION OF STREWS AND SMEARS

Individual grains or particles of sand, silt, oolites, and microfossils may be studied in detail by preparing strews or smears of the objects on small strips of acetate film. In preparing samples of sand or granule size, a small portion of the sample is spread on a glass or other smooth

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by solution. Fig. 2.—Crevice type void in Ozarkian dolomite, with well-developed intercrystalline voids. Fig 3.—Porosity formed by solution of oolites; Lansing-Kansas City Limestone, western Kansas ×25. Fig. 4.—Large vug-like voids produced by solution enlargement of primary intercrystalline voids. Note outlines of dolomite rhombs. Fig. 5.—Sand grains, beach sand, Ipswich Light, Mass. Fig. 6.—Intergranular porosity, Gunter sandstone, southern Missouri.

surface to the desired density of grains. A small strip of the acetate film is moistened with solvent and pressed onto the strewn grains, imbedding them in the softened film. After a few minutes of drying, the acetate strip is mounted in the cardboard slide mount described previously.

When projected, sand grains will appear translucent to transparent, and details of angularity, chatter marks, frosting and pitting can be clearly seen (pl. 1, fig. 5.). Cleavage planes, grain shapes, colors and other features of the translucent minerals can be readily identified provided the grain is not too thick for some transmission of light. However, opaque minerals will appear black, and may be identified only if they possess a distinguishing crystal or cleavage outline.

Particle counts of various grains of component minerals may be made, and counts of particles of varying sizes can also be readily made. Measurements of degree of rounding of grains are facilitated by the high magnifications of the projected images. Recently the writer had occasion to use the grain-projection method for a detailed study of roundness and two-dimensional sphericity of sand grains. Several thousand representative sand grains were studied in detail in a very short time by preparing an enlarged copy of the roundness chart developed by Rittenhouse (1943), with average grain size enlarged to a diameter of one inch. The projector and screen were set up to give a projected image of the same average size. By moving the roundness chart across the image of each sand grain, visual comparisons of degree of rounding were made with speed and accuracy.

OTHER APPLICATIONS OF THE METHOD

The projection system here described is also effective in the projection of thin sections of rocks and fossils, Thin sections of fusulinids, conodonts, arenaceous Foraminifera, and the larger diatoms can be examined in detail at magnifications

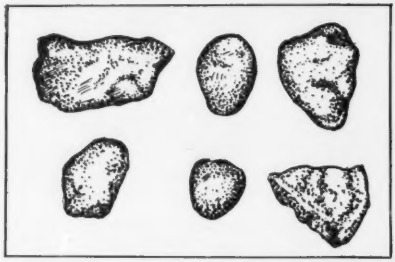

FIG. 1.—Tracings made from projected images of sand grains of various types. Drawings were shaded in pencil during projection and stippled later. ×30.

up to 500 diameters by using the special microprojector. The writer recently found that, in working with Pleistocene and recent Ostracoda, the near transparency of the valves of the carapaces makes delineation of the muscle scar patterns rather difficult. However, by mounting the specimens on acetate films and projecting them at magnifications up to 400 diameters, the muscle scar patterns could be easily distinguished, and traced off the projected image.

In the field examination of recent fine-grained sediments such as those of beach sands, dunes, and sand bars, it is often desirable to preserve the petrofabric orientation of the grains or particles on a given depositional surface. Acetate film strips, moistened with solvent, can be pressed on to the sand or silt layer and the uppermost layer of grains entrapped into the film, their orientation undisturbed. Orientation arrows and similar designations are carefully marked on the cardboard slide mount, and the specimens brought to the microscope or microprojector for detailed study.

PERMANENT RECORDING OF PROJECTED IMAGES

Projected images of strews, smears, and acetate replicas may be recorded permanently either by tracing the image on paper, or by photographic means.

Outline drawings of grain shapes and of

FIG. 2.—Inked tracing of solution voids in Cambro-Ordovician dolomite. Voids appear black. Note outline of dolomite crystals (rhombs). ×30.

porous voids and details of microfossils, etc., can be made by placing a sheet of drawing paper against the surface onto which the image is being projected, and tracing off the desired features (figs. 1 and 2). The writer has found that, by placing the microprojector on some sort of vertical support, such as a ring stand, and projecting the image downward on to a white surface on a table top, tracings and drawings can be made with ease and convenience. Vertical projection does limit the magnifications which can be obtained; however, magnifications up to and exceeding 500 diameters can be obtained by horizontal projection in a classroom or laboratory.

If it is desired to view or trace projected images in a room which does not have facilities for darkening, the projector may be housed in a simple cardboard box mounting such as is shown in figure 3. The box is approximately 30 inches in height and 15 inches square. The projector is mounted vertically, with the lens mount projecting through a hole cut into the upper end of the box. A small door is cut into the side of the box opposite the end of the lens, to facilitate focussing. The image is projected onto a sheet of white cardboard, and may be viewed in a lighted room by using this type of projector mounting.

Photographic methods may also be used for permanently recording microprojection images. The acetate film replicas may be satisfactorily used as negatives in making photographic enlargements. The replica film is removed from the cardboard mount and remounted securely in a glass 2 inch slide mount of the type used in mounting 35 mm color slides. The replica may then be placed in the negative carrier of the enlarger, and projected onto film or paper. Positive prints may be obtained by the use of direct-positive paper, or the image may be exposed on film of moderate contrast for lantern slide. It has been found that direct enlargement of the replicas of pore spaces and voids, using regular projection paper, produces a print wherein the voids appear as dark gray or black

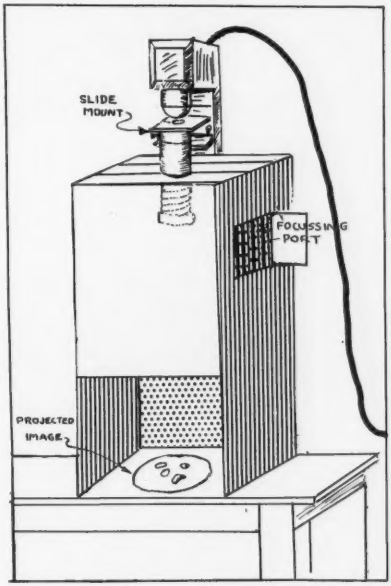

FIG. 3.—Sketch of cardboard box projector mounting for using microprojector in lighted room.

areas, and are readily seen. (See pl. 1, figs. 1, 2, 3, 4, and 6.) Strews of sand grains imbedded in acetate film may be also used in the enlarger and the image projected onto film. Prints are made from the negative obtained. In some instances, however, the area of acetate film which is in focus is rather small due to irregularities in the acetate surface. Tracing of the image on to drawing paper mounted on the projection surface is recommended for the strews and smears of sand grains.

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TESTING GRAPHICAL METHODS OF GRAIN-SIZE ANALYSIS OF SANDSTONES AND SILTSTONES[1]

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ABSTRACT

Graphical methods for the determination of standard deviations of grain-size distributions have been proposed by Otto (1939) and Inman (1952). A mathematical test based on Students' "t" distribution is suggested for comparing computed standard deviation or other parameters of a grain-size distribution with those determined by graphical short-cuts. Differences between computed standard deviations and those determined by Inman's graphic method show a probability of less than 0.001 of occurring in a normal population. A slight modification of Inman's formula raises the probability to less than 0.05 but greater than 0.02.

The computations necessary for a statistical analysis of the grain-size distribution of sandstones and siltstones are tedious and time-consuming. To save time, several sedimentologists have attempted to work out formulas for graphic shortcuts which produce results comparable with the computed results. G. H. Otto (1939) introduced the use of probability paper, and using it with the phi scale of Krumbein (1934), suggested graphical methods for determining some parameters of the phi distribution of the grain-size of a sand. The latest contributions in the direction of graphical shortcuts have come from D. L. Inman (1952) who has also made use of probability paper and phi units to determine the phi mean, standard deviation, a skewness coefficient, and a kurtosis coefficient. He also suggested recording the cumulative distribution curve of the grain-size of a sandstone in terms of the 5th, 16th, 50th, and 95th percentiles.

The problem of justifying the graphic method is well covered by the Inman article, but despite the thorough discussion of the theoretical background of statistical measures of properties of grain-size distributions, the graphical method of approximating the phi standard deviation proposed by Dr. Inman gives rise to serious discrepancies in practice. Although it is true that the standard deviation computed from data moments in the manner illustrated by Krumbein and Pettijohn (1938) is an approximation of the theoretical standard deviation, this approximation is usually the most precise measure that can be worked out by the student of sediments who studies a large number of samples.

Any shortcut, such as a graphical method for determining the standard deviation, should give results comparable with the results obtained from data moments, so that the shortcut may be tested statistically for any particular group of sediments by any interested student even if he is not particularly versed in statistical theory. To evaluate the graphic methods of Otto, Inman and others, it seems appropriate at this time to introduce a mathematical test which may be applied to the results of the graphic method as compared with the computed results.

The writer has accumulated more than 900 grain-size analyses of sandstones and siltstones that range in geologic age from the Cretaceous to the Permian. The data were accumulated as a part of the work being done on behalf of the Atomic Energy Commission. The samples were obtained in the Colorado Plateau region of Colorado, Utah, Arizona, and New

[1] Publication authorized by the Director, U. S. Geological Survey, and by the Atomic Energy Commission.

Mexico. Most of the analyses were made on samples of sandstone from the Morrison formation of Jurassic age. The analyses were obtained by sieving the sand fraction (2 mm to 1/16 mm) at quarter-phi intervals and pipetting the fine fraction (<1/16 mm) at phi intervals down to the one-micron-sized clay particles. The phi mean, standard deviation, skewness, and kurtosis were computed from moments using unit phi class intervals.

To test the graphic method proposed by Inman, 20 data sheets were selected from the files according to a predetermined numerical sequence (that is, randomization) and the phi standard deviations were computed using the proposed graphic method. The moment standard deviations and the standard deviations determined graphically were paired and their differences compared statistically by means of a test based on Student's "t" distribution similar to one shown by Snedecor (1946).

The procedure is shown in detail in table 1. The standard deviations computed from moments are labeled X_1; those obtained graphically are labeled X_2. The differences (d) are listed in the third column. The graphically obtained standard deviations were, with a single exception, found to be consistently smaller than the standard deviations computed from moments, with differences (X_1–X_2) ranging from minus 0.39 phi to plus 1.09 phi. Applications of Student's "t" distribution shows the probability of a deviation (t) greater than that found in this test occurring by chance in paired samples drawn from the same populations is less than 0.001 or one time in a thousand. Using a 95 per cent level of significance, which would mean that we would accept as significant any difference with a probability of occurrence of 0.05 or less, we must reject the hypothesis that the graphic method proposed by Inman produces results that are not significantly different from results obtained by use of data moments. In other words, it is highly probable that

TABLE 1.—*A "t" test to test the differences between σφ determined by moments and σφ determined by Inman's graphical method*

Sample No.	(X_1) Moment $\sigma\phi$	(X_2) Inman $\sigma\phi$	(d) Difference (X_1-X_2)	(d^2) Difference^2
L 80	0.83	0.61	0.22	
L 180	1.81	1.41	0.40	
L 280	0.82	0.41	0.41	
L 380	1.27	1.17	0.10	
L 480	3.14	3.53	−0.39	
L 580	0.94	0.43	0.51	
L 680	1.34	0.44	0.90	
L 780	1.39	0.65	0.74	
L 880	1.70	0.86	0.84	
L 40	0.57	0.36	0.21	
L 140	0.81	0.46	0.35	
L 240	1.03	0.44	0.59	
L 340	1.26	0.56	0.70	
L 440	1.85	1.79	0.06	
L 540	1.12	0.86	0.26	
L 640	1.53	0.73	0.80	
L 840	1.70	0.61	1.09	
L 940	0.84	0.39	0.45	
L 400	1.05	0.48	0.57	
L 800	1.42	0.68	0.74	
Sum	26.42	16.87	9.55	6.8409
Mean	1.3210	0.8435	0.4775	

$m=0$

$DF=19$

$$t=\frac{\overline{X}-m}{Sd}=\frac{\overline{X}_1-\overline{X}_2}{\left[\dfrac{\sum(X_1-X_2)^2-\dfrac{(T_1-T_2)^2}{N}}{N(N-1)}\right]^{1/2}}$$

$$t=\frac{1.3210-0.8435}{\left[\dfrac{6.8409-\dfrac{(26.42-16.87)^2}{20}}{20(19)}\right]^{1/2}}$$

$$=\frac{0.4775}{\left[\dfrac{6.8409-4.5601}{380}\right]^{1/2}}$$

$$t=\frac{0.4775}{0.0775}=6.161.$$

Probability of a deviation greater than "t" occurring by chance in a normal distribution is less than 0.001.

deviations determined by the Inman method are not comparable with those determined from data moments.

The large differences between paired deviations are probably due to skewness of the distributions. A failure to respond to moderate skewnesses is one of the limitations of the graphic method as Inman points out; however, moderate skewness may well be a common property of many sediments.

Assuming that the reason for this failure of the graphic method using the 16th and 84th percentiles, a spread of two standard deviations, is due to a lack of sensitivity to variations at the end of the distribution, the writer tried the graphic method, using the 2d and 98th percentiles to see if a closer approximation could be achieved. The spread between the 2d and 98th percentiles was arbitrarily given a value of four standard deviations. The computation involved the formula $\frac{1}{4}(\phi_{98}-\phi_2)$ as compared with Inman's formula $\frac{1}{2}(\phi_{84}-\phi_{16})$.

Phi standard deviations were recomputed for the 20 test samples using the modified formula. The results were paired with the standard deviations computed from moments and the differences computed as before. The differences were subjected to the same statistical test (table 2) to see if greater differences might occur by chance between paired samples taken from the same populations.

The standard deviations computed by the modified graphical method were found to be on the average larger than those computed from data moments. The mean difference between pairs was found to be about 0.14 phi and to range from minus 0.65 to plus 0.23. Application of Student's "t" distribution shows that the probability of a deviation (t) greater than that found in the test occurring by chance between paired samples drawn from the same populations is less than 0.05 and greater than 0.02, that is less than 5 times in a 100 and greater than 2 times in a 100.

Using a 95 percent level of significance, we can accept the hypothesis that the

TABLE 2.—*A "t" test to test the differences between σφ determined by momemts and σφ determined by a modification of Inman's graphical method*

Sample Mo.	(X_1) Moment	(X_2) Inman (modification)	(d) Difference (X_1-X_2)	(d^2) Difference^2
L 80	0.83	0.81	0.02	
L 180	1.81	1.95	−0.14	
L 280	0.82	0.80	0.02	
L 380	1.27	1.23	0.04	
L 480	3.14	2.91	0.23	
L 580	0.94	0.90	0.04	
L 680	1.34	1.68	−0.34	
L 780	1.39	2.04	−0.65	
L 880	1.70	2.32	−0.62	
L 40	0.57	0.46	0.11	
L 140	0.81	0.68	0.13	
L 240	1.03	1.18	−0.15	
L 340	1.26	1.56	−0.30	
L 440	1.85	1.79	0.06	
L 540	1.12	0.93	0.19	
L 640	1.53	2.08	−0.55	
L 840	1.70	2.20	−0.50	
L 940	0.84	0.80	0.04	
L 400	1.05	1.21	−0.16	
L 800	1.52	1.68	−0.26	
Sum	26.42	29.21	−2.79	1.8275
Mean	1.3210	1.4605	−0.1395	

$m=0$

$DF=19$

$$t=\frac{\bar{X}-m}{s\bar{d}}=\frac{\bar{X}_1-\bar{X}_2}{\left[\dfrac{\sum(X_1-X_2)^2-\dfrac{(T_1-T_2)^2}{N}}{N(N-1)}\right]^{1/2}}$$

$$t=\frac{1.3210-1.4605}{\left[\dfrac{1.8275-\dfrac{(26.42-29.21)^2}{20}}{20(19)}\right]^{1/2}}$$

$$=\frac{-0.1395}{\left[\dfrac{1.8275-0.3892}{380}\right]^{1/2}}$$

$$t=\frac{-0.1395}{0.061}=-2.286$$ (minus sign has no meaning; disregard)

Probability of a deviation greater than "t" occurring by chance in a normal distribution is less than 0.05 and more than 0.02.

TABLE 3.—*Descriptive measures, listed in phi notation, of the 20 samples used in this paper*

Sample No.	Mean	Standard deviation	Skewness	Kurtosis	ϕ_2	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	ϕ_{99}	Formation
L 40	2.793	0.570	0.368	−0.381	2.08	2.27	2.51	2.84	3.23	3.53	3.92	Morrison formation
L 80	3.141	0.677	0.242	3.736	1.57	1.99	2.53	3.12	3.75	4.35	4.81	Carmel formation
L 140	1.882	0.811	1.912	22.961	1.10	1.20	1.40	1.77	2.31	2.90	3.82	Dakota sandstone
L 180	4.086	1.814	0.655	1.469	1.83	2.02	2.55	3.78	5.36	8.28	9.63	Summerville formation
L 240	3.070	1.029	1.728	16.541	2.02	2.22	2.50	2.93	3.37	4.07	6.75	Morrison formation
L 280	3.593	0.819	2.042	24.496	2.62	2.81	3.06	3.37	3.87	4.50	5.80	Navajo sandstone
L 340	3.145	1.259	1.603	11.636	2.22	2.34	2.50	2.83	3.62	5.33	8.45	Morrison formation
L 380	2.679	1.273	0.430	1.538	0.83	1.02	1.47	2.53	3.81	4.86	5.76	Morrison formation
L 400	2.945	1.054	1.806	18.022	1.81	2.07	2.42	2.78	3.37	4.07	6.65	Morrison formation
L 440	6.482	1.848	0.125	−0.262	3.29	3.95	4.74	6.15	8.31	9.64	10.45	Burro Canyon formation
L 480	6.101	3.137	0.211	−1.281	2.49	2.57	2.95	5.30	10.01	12.65	14.13[a]	Morrison formation
L 540	2.031	1.118	1.246	10.479	0.76	0.91	1.22	1.78	2.94	3.72	4.47	Morrison formation
L 580	3.084	0.943	1.900	21.917	1.73	2.26	2.54	2.98	3.40	3.85	5.32	Morrison formation
L 640	2.684	1.531	1.585	13.090	1.18	1.38	1.77	2.37	3.22	4.76	9.50	Morrison formation
L 680	2.355	1.336	1.778	16.517	9.03	1.26	1.69	2.11	2.57	4.15	7.65	Morrison formation
L 780[b]	3.049	1.390	1.870	16.586	1.83	1.98	2.27	2.74	3.57	4.42	10.00	Cow Springs sandstone
L 800	2.932	1.422	1.492	11.067	1.55	1.72	2.06	2.63	3.42	5.55	8.29	Morrison formation
L 840	2.766	1.702	1.703	12.763	1.31	1.53	1.89	2.38	3.10	5.92	10.09	Morrison formation
L 880	2.346	1.698	0.415	4.566	−1.77	−0.38	1.36	2.33	3.08	5.60	7.52	Shinarump conglomerate
L 940	4.147	0.840	1.502	14.709	3.37	3.49	3.72	4.03	4.50	4.98	6.57	Cutler formation

[a] Extrapolated.
[b] Sample L 740 was not analyzed.

modified graphic method produces results that are significantly different from results obtained by use of data moments. In other words the results of these two methods are not comparable.

To summarize, it may be concluded that, on the basis of a 95 per cent significance level, the use of Inman's graphic method for obtaining the phi standard deviation using the formula $\frac{1}{2}(\phi_{84}-\phi_{16})$ would probably yield results that would be significantly different from those obtained from the computation of moments of grain-size distributions similar to those used in the "*t*" tests. For this reason, the deviations determined by Inman's method could not be referred to as equivalent approximations of those determined by computation.

It is probable that the modified graphic method using the formula $\frac{1}{4}(\phi_{90}-\phi_{2})$ and applied to grain-size distributions similar to those used in the "*t*" tests would also yield phi standard deviations that would be significantly different from those obtained through the computation of data moments.

The 95 per cent level of significance used by most workers would lead to the rejection of both methods for producing results comparable to those obtained from moment calculations; however, comparing the two graphic methods, it is apparent that the results of the modified graphical method can be considered as nearly comparable with those of the moment calculations and are much closer to the calculated values than the results of Inman's original graphical method.

If a rapid method is required for obtaining the standard deviation of a distribution, the graphical method proposed by Inman, but using the formula $\frac{1}{4}(\phi_{98}-\phi_{2})$, will provide a reasonably approximate but not directly comparable measurement.

The writer is in full accord with Dr. Inman's objectives to standardize the reporting of descriptive measures of grain-size distributions. The idea of transmitting raw grain-size distribution data in the form of critical percentiles is a good one and would be amended by this writer only to the extent of adding the 2d and 98th percentiles to the list in spite of the recognized large range of error at these points on the curve.

The descriptive percentiles of the 20 samples used in this paper and descriptive measures computed from data moments are listed on table 3.

This paper was submitted to J. C. Griffiths, Associate Professor of Mineralogy, Pennsylvania State College, for critism and comment. The writer, however, assumes full responsibility for all statements made in the paper. Table 1 was submitted to the Iowa State College Statistical Laboratory for comment on the use of Student's "*t*" test where the method was checked by Assistant Professor Ray Mickey.

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JUNE, 1954

ABSTRACTS OF PAPERS
TWENTY-EIGHTH ANNUAL MEETING
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

The Twenty-eighth Annual Meeting of the Society of Economic Paleontologists and Mineralogists was held in St. Louis, Missouri, on April 12–15, 1954. Some of the sessions were held jointly with the American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

Society officers for the year April, 1954–March, 1955 are as follows:
President: HANS E. THALMANN, Stanford, California
First Past-President: HAROLD N. FISK, Houston, Texas
Second Past-President: CLIFFORD C. CHURCH, San Francisco, California
Vice-President: FRANCIS J. PETTIJOHN, Baltimore, Maryland
Secretary-Treasurer: SAMUEL P. ELLISON, JR., Austin, Texas
Editor, Journal of Sedimentary Petrology: JACK L. HOUGH, Urbana, Illinois
Acting Editor, Journal of Sedimentary Petrology: RALPH E. GRIM, University of Illinois, Urbana, Illinois
Editor, Journal of Paleontology: GROVER E. MURRAY, Louisiana State University, Baton Rouge, Louisiana

JOINT SESSION WITH A.A.P.G. AND S.E.G.

April 13, 9:00 to 12:00 A.M.

PRESIDENTIAL ADDRESS

Presiding for S.E.P.M.: MARCUS A. HANNA

THE S.E.P.M. LOOKS AHEAD

HAROLD N. FISK
Humble Oil and Refining Company, Houston, Texas
President, Society of Economic Paleontologists and Mineralogists

In the quarter century since its organization, the S.E.P.M. has proved its worth to the geological profession in many ways. The Society now forms one of the strongest ties between the economic and academic fields of geology. It stimulates research, offers a medium for exchange of ideas, and publishes journals of a high standard. These accomplishments reflect the value of its original objectives and the degree to which they have been met, and they indicate the future course to be pursued. To be of greatest service, the Society should conduct its affairs with as much independence as possible, and should make every effort to operate on a sound financial basis. It should increase its efforts to keep up with developments in stratigraphy and should strive to obtain the active participation of more paleontologists and petrologists by fostering the organization of regional sections. The Society will always require aggressive leadership, both at a central and regional level. To help assure this, the Research Committee is being expanded to be more representative of membership in the various sections of the country and will be given greater responsibility in the conduct of Society matters. Most of all, the Society must continue to encourage in every possible way the gathering and dissemination of stratigraphic information fundamental to our knowledge of the geology of petroleum.

MINERALOGY AND SEDIMENTARY PETROLOGY

April 13, 2:00 to 5:00 P.M.

Presiding: H. A. IRELAND AND D. H. EARGLE

LOWER PENNSYLVANIAN SEDIMENT SOURCES OF THE EASTERN INTERIOR BASIN[1]

RAYMOND SIEVER AND PAUL E. POTTER

Illinois State Geological Survey, Urbana, Illinois

Knowledge of the source of sediments is one of the keystones of any study of the origin of a group of sediments. The establishment of locations and types of sediment sources and estimates of the relative amounts of detritus supplied by each source are necessary in the regional study of any group of clastic rocks. Provenance is also important in many studies for an understanding of environmental processes.

Cross-bedding direction and sedimentary petrography were used to assess the provenance of basal Pennsylvanian orthoquartzites in the Eastern Interior Basin. Over 900 cross-bedding measurements from the Eastern Interior and Michigan basins and portions of the Appalachian Basin in Ohio, Kentucky, and Tennessee were used in determining the regional pattern of direction of sediment transport. The cross-bedding direction of the basal sandstone is related to the youthful topography of the Mississippian-Pennsylvanian unconformity. Evidence suggests that *the direction of both crossbedding and pre-Pennsylvanian channels is consequent on the regional slope from the source area.* Because of its intracratonic position the Eastern Interior Basin received sediment from the northern Appalachians and from eastern and western parts of the Canadian Shield.

Petrography was also used to evaluate these contrasting sources of supply. Over 200 thin-sections, distributed approximately one to every 12 miles of outcrop, were examined. The results of this study indicate three regional mineral associations that, in general, correlate with contrasting cross-bedding directions.

The major area of subsidence and sedimentation in earliest Pennsylvanian time was to the south and southwest of the Eastern Interior Basin; this area gradually expanded and progressed northward to the interior of the Continent.

[1] Published with permission of the Chief, Illinois State Geological Survey.

FACIES DEVELOPMENT AND INTERTONGUING IN THE BOOK CLIFFS OF EASTERN UTAH

ROBERT G. YOUNG

The California Company, Casper, Wyoming

Excellent exposures of Upper Cretaceous rocks in the Book Cliffs of eastern Utah exhibit complex intertonguing relations between four distinct facies. Rocks of the inland, lagoonal, and littoral marine facies of the Star Point and Blackhawk formations pass eastward into offshore deposits of the Mancos shale. These facies are present in a normal vertical and horizontal succession with some repetition due to the intertonguing produced by shifting environments. All these facies intertongue, but the most significant intertonguing is that between littoral marine sandstones and offshore marine shales.

In the western end of the Book Cliffs the Star Point sandstone consists of three littoral marine sandstone tongues which disappear eastward into the Mancos shale. Resting on the upper tongue (Spring Canyon tongue) are about 100 feet of coal-bearing rocks comprising the Spring Canyon coal member of the Blackhawk formation. This member is separated from the overlying Aberdeen member by a thin tongue of Mancos shale. These coal-bearing rocks are terminated eastward by two offshore bar sandstones which appear near the town of Helper. The coal-bearing rocks of the overlying members of the Blackhawk likewise formed behind such barriers, and are seen to terminate seaward behind other bars. These bars appear as small littoral marine sandstone tongues which pass into the marine shale to the east. The primary difference between them and the larger littoral marine sandstone tongues, which occur at various horizons in the Star Point and Blackhawk formations, is their lesser areal extent. All are regressive sandstones formed during the progressive eastward retreat of the Upper Cretaceous shoreline following sharp pulses of basinal subsidence of various magnitudes. The larger tongues formed following the greater subsidences. These were usually separated by several subsidences of lesser magnitude.

After the formation of each sandstone tongue, long periods of quiet conditions prevailed before the next subsidence. This is indicated by thick coal deposits which rest directly on the sandstone tongues or lie at position in the lagoonal deposits corresponding to the tops of the offshore bars.

THE PROCESS OF DEPOSITION OF THE SALINA SALT OF MICHIGAN

LOUIS F. DELLWIG

University of Kansas, Lawrence, Kansas

A comparison of the Salina salt of Michigan with solar salt and artificially produced grainer salt reveals similarities in the crystals which necessitate a parallelism of genesis. Additional information concerning the formation of bedded salt deposits is to be found in the petrographic examination of the so-called "jahresringe," and in temperature de-

terminations in the liquid inclusions in the halite.

The accumulated evidence indicates that seasonal or temperature changes are recorded in the alternating bands of clear (inclusion-free) and cloudy (inclusion-rich hopper crystals) salt. The anhydrite and dolomite laminae (jahresringe) are indicative of an influx of sea water into the basin of deposition. Evaluation of the indicated temperatures of deposition obtained from the liquid inclusions points to deposition at lower temperatures than have been called for by many workers in the past.

A COMPARATIVE STUDY OF UPPER CHESTER AND LOWER PENNSYLVANIAN STRATIGRAPHIC VARIABILITY[2]

PAUL E. POTTER AND RAYMOND SIEVER
Illinois State Geological Survey, Urbana, Illinois

A fundamental property of sediments is stratigraphic variability, whose quantitative study is long overdue. For any stratigraphic parameter, the analysis of variance in which the variance at different levels of sampling is computed and compared provides estimates of variability for increasing increments of area. In this study the analysis of variance is used to compare the homogeneity of Upper Chester sandstones and limestones with that of Lower Pennsylvanain sandstones.

Seventy-two electric logs were chosen at random from a 2916 square mile area of the Illinois Basin largely devoid of contemporaneous tectonism, subdivided as follows:

2 wells per section
2 sections per township
2 townships per supertownship
9 "supertownships" (one supertownship $=3\times3$ land survey townships)

Maximum variability in Pennsylvanian sandstones is between townships, the order of variability being: Wells < sections < townships > supertownships. These values are compared with Upper Chester sandstones and limestones. For Pennsylvanian and Upper Chester sandstones local hydrodynamic factors are probably chiefly responsible for variability between wells, environmental factors for sections and townships, and tectonic factors for supertownships.

Quantitative studies of stratigraphic variability provide confidence limits for various stratigraphic parameters. An example would be how accurately a given number of wells sample a section, a township, or a supertownship. Quantitative studies of stratigraphic variability have significance for correlation, for environmental and tectonic interpretation, and sedimentary differentiation.

[2] Published by permission of the Chief of the Illinois State Geological Survey.

STATISTICAL ANALYSIS OF FACIES PATTERNS

W. C. KRUMBEIN
Northwestern University, Evanston, Illinois

Facies maps based on two sets of contour lines (such as the clastic ratio and sand-shale ratio) may yield patterns with concordant or discordant ratio lines. Selected areas on the maps may be tested for "facies homogeneity" of the individual ratios by ordinary analysis of variance techniques, and multivariate analysis of variance may be used for simultaneous study of both ratios. The methods are applicable to regional or local studies, and examples are given of Pennsylvanian studies from several Midcontinent areas. Application of the technique permits recognition of "facies populations" which in some instances may have economic importance, as for example along basin margins or in areas of sand pinchout along structural flanks.

SEDIMENTATION PHENOMENA IN A MOUNTAINOUS SOURCE AREA

F. ALTON WADE
Miami University, Oxford, Ohio

A detailed investigation was made of lateral deposits of sediments along the course of a youthful stream which is eroding a small section of the eastern flank of the northern end of the Wind River Mts. in northwestern Wyoming. Variations in mineral composition, grain size, roundness, sphericity, and surface features were determined, studied, and correlated with each other and with variations in the source rocks in the immediate vicinity of and upstream from each deposit. As the stream is receiving its load in part from primary granite and in part from Paleozoic and Quaternary sediments, the deposits are mixed first- and higher-cycle detritals. Such a source environment is common in the Rocky Mountains, and a great percentage of the clastics presently being deposited in the Great Plains area is obtaining diagnostic characteristics because of modifications which take place during the first few miles of transport.

SEDIMENTARY CHARACTERISTICS OF PRODUCING ZONES IN WEST BROCK AREA, CARTER COUNTY, OKLAHOMA

L. L. SLOSS AND E. C. DAPPLES
Northwestern University, Evanston, Illinois

The West Lone Grove, Bayou, and West Brock fields lie along a structural axis trending southeast from the Hewitt anticline to the Criner Hills uplift, Closely spaced drilling and excellent electric log control provide data for detailed analysis of the producing zones and their relation to structural growth. The

section concerned is the Deese, including the so-called "Lone Grove series." A cyclical succession, dominated by shale but including numerous sand bodies and minor limestones, is involved. The cycles are identified with their limestone members as recognized in outcrop.

Sands in the upper part of the section are shown to have a broad "blanket" distribution pattern with production confined to higher parts of closed structures. As the base of the Deese is approached discontinuous sand bodies are present and these have an irregular distribution of productive areas with respect to structure. Maps of numbers of sands, net sand thickness, and average sand thickness show a systematic pattern which is clearly related to the structural trend. Off-structure areas are characterized by high sand thicknesses with large numbers of sands present; higher areas exhibit small or gross amounts of sand confined in fewer individual bodies. In addition, the structurally higher areas are characterized by high rates of change in thickness and number. A combination of rates of subsidence with such environmental factors as waves and currents is invoked to explain the distribution patterns. The characteristics expressed within individual sands may be tested statistically for identification of significant variations.

PETROLOGY OF SPRINGER OIL BEARING SANDSTONES

LYNN JACOBSEN
University of Kentucky, Lexington, Kentucky

The oil bearing sandstones of the Springer formation in several large southern Oklahoma oil fields seem to be petrographically distinct from the non-oil bearing ones. In general they are coarser grained and more massive; they do not have a clay matrix, and characteristically they have placer-like concentrations of heavy minerals.

Siderite and pyrite are common in the Springer formation as a whole but are absent from the reservoir sandstones. Calcite, however, occurs with the reservoirs—as clastic grains and to a small extent as cement in the sandstones, and as interbedded thin limestone layers. These associated limestones are either oolitic or debris of benthonic fauna.

The major occurrences of the reservoir type sandstones are on several large anticlinal uplifts, and the sandstones lose their distinctive character down the flanks of the anticlines. Slumped bedding is common on the anticlinal flanks. The character of the reservoir facies and the association of structure with rock type suggests that the loci of the distinctive sedimentation of the oil bearing sandstones was on topographic highs formed by early movements of the uplifts.

It is suggested that the distinctive sandstone is the critical factor in the accumulation of the oil, and hence, that large Springer oil production will be found only on uplifts with a history of movements during sedimentation.

THE ORIGIN OF NATIVE SULFUR IN THE GULF COAST SALT DOMES

J. LAURENCE KULP
Lamont Geological Observatory, Palisades, New York

New light has been shed on the origin of the native sulfur in the Gulf Coast salt domes by measurements of the ratios S^{32}/S^{34} in sulfur compounds and C^{12}/C^{13} in the carbonate cap. In addition quantitative laboratory experiments have been performed in attempts to synthesize sulfur on H_2S from sulfate under the conditions of temperature, pressure, and composition existing in the salt domes. These experiments demonstrate that the inorganic reduction of sulfate is a very improbable hypothesis for the time available. The fractionation observed in the sulfur isotopes between the sulfate and the sulfur in the cap rock is in the same range as that produced by bacteria under similar conditions in the laboratory. The C^{12}/C^{13} ratios in the carbonate cap of sulfur producing domes is in the range of organic carbon, not normal limestone. These new facts suggest that the origin of the sulfur takes place first by the bacterial reduction of sulfate to H_2S with hydrocarbons as an energy source, after which the H_2S is reduced to native sulfur by the reaction with sulfate ion. The correlation of this mechanism of sulfur formation permits prediction of the most likely domes or areas of domes for future explanation.

A SIMPLE CORING TUBE FOR SOFT SEDIMENTS[3]

MARCUS A. HANNA
Gulf Oil Corporation, Houston, Texas

A simple hand operated core barrel with following features:

1. Operated by one or two men depending on length of core cut and depth of water.
2. Relatively light weight.
3. Double tube barrel, inner plastic tube and core easily removed.
4. Ball check valve in top of inner tube eliminates need for core catcher.
5. Has been used in water 15 feet deep.
6. Cutting core causes almost no turbidity in water on top of core resulting in excellent cores for skin studies.
7. Cuts $2\frac{3}{4}$ inch O. D. cores but design can be used for other diameters.

[3] Presented with permission of Gulf Oil Corporation.

MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY IN NORTH-EASTERN UTAH

WALTER SADLICK

University of Iowa, Iowa City, Iowa

Stratigraphic paleontologic investigation of the Mississippian "black shale unit" and the overlying lower lime member of the Pennsylvanian Morgan formation in the Uinta Mountains has yielded evidence concerning the position of the Mississippian-Pennsylvanian boundary in Utah. The black shale unit contains *Cravenoceras nevadense* Miller and Furnish, *Neospirifer* aff. *N. cameratus* (Morton), *Dictyoclostus* cf. *D. coloradoensis* (Girty), ostracodes, and at the base a pinnule similar to *Cardiopteris hirta* White. This assemblage is similar to that of the Fayetteville formation of Arkansas. *Rhipidomella nevadensis* (Meek) overlies this fauna in the upper beds of the Manning Canyon shale of the Great Basin but it has not been found in the black shale unit. Present evidence suggests a correlation of the black shale unit with the Manning Canyon black shale of the Great Basin, and the apparent absence of the *Rhipidomella nevadensis* zone suggests a disconformity between the Manning Canyon shale of the Uinta Mountains and the overlying lower lime member of the Morgan formation. The uppermost 1,100 feet of the Brazer formation in the Dry Lake section, 15 miles southwest of Logan, is lithologically similar to the type Manning Canyon shale and contains near the top the *Riphigodmella nevadensis* zone, suggesting a direct correlation.

The lower lime member of the Morgan formation has been traced to beds in the eastern Uintas tentatively assigned to the Belden formation by Thompson on the basis of fusulinids. The fossils, which are partly replaced by jasper, include *Wellerella osagensis* (Swallow), spiriferoids of the group of *S. rockymontanus-opimus-matheri-occidentalis, Cleiothridina orbicularis* (McChesney), and *Composita ozarkana* Mather, in addition to ostracodes and forams that indicate a Morrowan age. The lower lime member has been traced to the type section of the Morgan formation and is found to underlie it; furthermore, it has been included as a part of the Brazer formation by previous geologists. Since this lower lime member is a distinct lithologic unit, a new name is being proposed in a forthcoming publication. The lower 1,200 feet of the Oquirrh formation of the Great Basin contains a fauna similar to that found in the lower lime member of the Morgan formation suggesting that these stratigraphic units are partly equivalent in age.

JOINT TECHNICAL SESSION WITH A.A.P.G. AND S.E.G.

April 14, 9:00 to 12:00 A.M.

PAPERS OF GENERAL INTEREST

Presiding for S.E.P.M.: W. T. ROTHWELL, JR.

EXPLORATORY DRILLING IN 1953

FREDERIC H. LAHEE

Sun Oil Company, Dallas, Texas

During 1953, 13,304 exploratory holes were drilled in the United States. Of these, 6,925 were new-field wildcats, the rest being new-pool tests and outposts. Among the total 13,304 exploratory holes, 2,671 were successful or 20.1 per cent. Among the new-field wildcats, 774 were successful, or 11.2 per cent.

A total of 60,701,899 feet were drilled in exploratory holes in 1953, or an average of nearly 4,563 feet per hole. For comparison, in 1952 the total number of exploratory holes drilled was 12,425, and the total exploratory footage was 55,615,389 feet.

In Canada in 1953, 3,898,901 feet were drilled in 986 exploratory holes, of which 265 holes were successful. These figures compare with 3,667,085 feet drilled in 988 exploratory holes in 1952, when 251 of these holes were successful.

SIGNIFICANT EXPLORATORY DEVELOPMENTS OF 1953

PHILLIP C. INGALLS

Socony-Vacuum Oil Company, Inc., New York, New York

The results of wildcatting in the United States' active oil frontiers of 1953 demonstrated that the current optimistic predictions for those big, sparsely tested areas are not just wishful thinking.

During 1953, exploratory thinking was further broadened and brightened by the completion of oil or gas-producing wildcats across the country. Some of these discoveries were in the wide-open spaces, others hugged or were within areas of big production; some were completed as significant producers, others made only small wells but afforded concrete evidence of the potentialities of a hitherto unproductive area or formation.

None of these wildcat discoveries can yet be recognized as indicating an exceptionally

large reserve. It will take development drilling during the next few years to determine how much oil and gas were found. But, regardless of the final tally, the discoveries resulting from last year's unprecedented reaching out and down into the unknown have stimulated further exploratory efforts that will lead to more major oil and gas fields.

INTRODUCTION TO THE OIL AND GAS GEOLOGY OF THE GREAT PLAINS REGION

THEO. A. LINK
Downing & Cooke Ltd., Toronto, Ontario and Calgary, Alberta

The Great Plains area of North America, which lies immediately to the east of the Great Cordilleran Mountain Ranges, will be the subject of a Symposium to be conducted during this meeting Thursday afternoon. Before any considerable amount of surface geological mapping had been undertaken by the pioneers of North American geology this Great Plains area was regarded as essentially a simple basin area of relatively undisturbed sedimentary rocks—with only obvious anomalies such as the Black Hills, Little Rocky, Bearpaw and Highwood Mountains, Sweet Grass Hills, etc. As more data became available, through additional surface geological surveys, subdivisions of this area began to appear in the literature. With the advent of the petroleum geologist (soon after the turn of the century) and with his more detailed surface geological mapping, drilling of deep tests, aerial photography, geophysical surveys, etc., more subdivisions were made, and still more will be made as more data become available through the search for more oil and gas. To cover adequately the various structural and/or sedimentary subdivisions of the Great Plains area of North America would require a great deal more time than allotted to this Symposium, but contributions representative of the large amount of detailed information which is becoming available in this area will be presented during this session. This particular contribution is to serve the purpose of a brief outline of the Great Plains area, and is not intended to convey local details.

GEOLOGIC FRAMEWORK OF THE GULF COASTAL PLAIN OF TEXAS

J. A. WATERS, P. W. MCFARLAND, AND J. W. LEA
Sun Oil Company, Dallas, and Corpus Christi, Texas

The area represented by the Gulf Coastal Plain of Texas is bounded updip by the outcrop of the oldest Upper Cretaceous beds, downdip by the outer margin of the present continental shelf, east and west by the Louisiana State line and the Rio Grande. Paralleling the inner margin of the coastal plain and beneath beds of Cretaceous age lies the Ouachita folded belt. These partially truncated Ouachita folds served in part as the foundation on which the Mesozoic and Cenozoic sediments were deposited.

Regional tectonics controlled the ancient geological features and their associated sedimentary processes. Peneplanation at the close of some periods was followed by intense rejuvenation of the land areas which resulted in long periods of deltaic activity. This, together with the downwarping, faulting, and slumping along the successively younger continental shelves resulted in structural conditions, blanket and lensing sands which offer ideal conditions for the trapping of oil and gas. The closed basins and embayments received evaporites and/or reef development to a minor degree. The migration of the geosyncline southward to its present position with each period of deposition resulted in the great thickness of sediments underlying the Gulf Coastal Plain.

The structural, isopach and isolith maps based on the deepest well control permit conclusions about the following: (1) The present structural position of the formations from the beginning of the Jurassic to the close of the Miocene Epoch, (2) the thickness and rate of thickening of these sediments gulfward indicating the structural position of the top of each formation on which each succeeding formation was laid down, and (3) the ratio of sand to shale showing the regional facies changes, which combined with stratigraphy may be interpreted as geologic sedimentary features.

THE PRESENT STATE OF GEOTHERMAL INVESTIGATIONS

FRANCIS BIRCH
Harvard University, Cambridge, Massachusetts

At present, the emphasis in geothermal studies in nonvolcanic areas is on the flow of heat to the surface, a quantity of much theoretical importance. The number of reliable determinations of heat flow is still small, with few of the oil-producing regions represented. While thermal gradients range from about 5 to 70°C/km, most of the measurements of heat flow fall within the range, $1.2 \cdot 10^{-6}$ cal/cm.^{2} sec $\pm 50\%$, including the recent values for the deep ocean basins. There are suggestions of regional variations, but many more measurements reliable to 10% or better will be needed for further progress. The study of geological regions or provinces, rather than single localities, is especially desirable, and should be feasible in areas extensively drilled

for oil. The principal requirements which are difficult to meet are (1) approximate thermal equilibrium, which usually requires an undisturbed period of many months, and (2) availability for laboratory study of cores representing the major formations penetrated by the well. A renewal of interest in this subject among oil geologists, with recognition and exploitation of opportunities as they arise, could greatly advance its development.

A SEISMIC-REFLECTION QUALITY MAP OF NORTH AMERICA

PAUL L. LYONS
Anchor Petroleum Company, Tulsa, Oklahoma

A reflection quality map of North America has been prepared by a subcommittee of the Program and Arrangements Committee for 1953–54. The map brings to date the map of the United States prepared for the April meeting of the SEG in 1951, and the remainder of the continent has been added. The map designates as good, fair, or poor to NG all sedimentary areas of the continent in respect to reflection quality in conventional seismic explorations. A ready correlation is apparent between the areas of intensive oil and gas development and areas of fair to good reflection quality. The rapid oil and gas developments in recent years in western Canada may be directly ascribed to the unexpectedly good seismic data obtained. The committee notes the invasion of the poor to NG areas by the use of special techniques and the reward to be gained by progress in this direction, for approximately half of the sedimentary area of North America yields poor to NG reflections.

THICKNESS MAPS AS CRITERIA FOR REGIONAL STRUCTURAL MOVEMENTS

WALLACE LEE
Kansas Geological Survey, Lawrence, Kansas

A map depicting the thickness of a sequence of rocks between surfaces that were once flat or relatively flat, records the structural movements that occurred between the development of the limiting surfaces. Such an isopachous map is essentially a structure map of the first surface at the time of the second. The accuracy with which such maps reveal the structural movements that took place during the interval depends on how closely the limiting surfaces approached a plane. The deformation is most accurately revealed where the confining surfaces were depositional. Erosional surfaces of low topographic relief may be used to reveal regional warping of broad areas. The relation of the sequence of rocks to underlying and overlying formations determines the time of movement. Isopachous maps that include sequences of formations whose thicknesses were separately controlled by conflicting patterns of folding express a composite of both movements and reveal neither.

OIL AND GAS PRODUCTION FROM CARBONATE RESERVOIRS

FRANK B. CONSELMAN
Consulting Geologist, Abilene, Texas

Non-reef carbonate reservoirs include some of the most famous and prolific oil and gas reservoirs in the world, despite the relative emphasis on reefoid masses in recent research and development programs. Approximately twenty to twenty-five per cent of the world's reserves are believed to be contained in non-reef carbonate rocks.

For general purposes, carbonates are classified broadly as of chemical, evaporative, biochemical, organic, and clastic origin, with examples cited. Although there are classic examples of limestones and dolomites which preserve their lithologic and stratigraphic character for thousands of square miles, probably the majority will exhibit some type of facies differentiation within relatively short distances, both vertically and horizontally. These facies changes provide excellent stratigraphic trap possibilities, even in non-reefed rocks.

Oil and gas reservoirs in carbonates may be caused by the structural deformation of rocks having widespread, relatively uniform, intergranular porosity; by the development of fracture and fissure systems at favorable positions with respect to fluid migration; and by permeability pinchouts in connection with facies changes.

Potentialities of carbonates as oil sources are not fully understood, but oil in minor quantities at least may be generated from certain facies.

Development practices in carbonate reservoirs are influenced by the characteristic irregularity of pore space, the chemical sensitivity of the rock to both natural and artificial leaching, and such physical characteristics as structural strength, rigidity and competency. Although internal differences from conventional sand reservoirs are marked, nevertheless it has been demonstrated that production histories of carbonate reservoirs provide almost identical patterns with sand reservoirs of comparable drive. Primary recovery estimates by volumetric methods necessarily contain large factors of error.

Secondary recovery programs are proving successful in carbonate reservoirs as well as in sands, but the effect of fracturing and channeling must be considered to avoid by-passing large reservoir volumes. Reservoir heating

techniques may prove to be applicable.

In future prospecting, applied sedimentology may have as large a field in the carbonate rocks as it has had in the clastics. Practical "trendology" will also be useful, in addition to the conventional fold-finding techniques which have dominated exploration methods in the past.

REGIONAL STRATIGRAPHIC ANALYSIS OF THE COTTON VALLEY GROUP OF THE UPPER GULF COASTAL PLAIN[4]

JAMES M. FORGOTSON, JR.
Northwestern University, Evanston, Illinois

Lithologic and thickness data on Upper Jurassic rocks of the Cotton Valley group, Upper Gulf Coastal Plain, were interpreted from electric and sample logs, and correlations were established from Arkansas and Louisiana into Texas, Mississippi, and Alabama.

Units mapped include the total Cotton Valley, the Schuler formation, and the Bossier formation. Maps included are based on isopachs, lithofacies, shale ratios, and vertical variability. Sand distribution in the Schuler is represented by a "number of sands" map, a "slice map" of the top thousand feet, and a "tripartite sand distribution" map.

The Bossier formation is a regional wedge of thick black shale merging updip into a fringe of non-marine shale and sand. The Schuler formation overlaps the Bossier. Its downdip aspect is predominantly marine. It thins updip through a transition zone of maximum shale percentage and maximum number of sands into a non-marine section of coarse clastics.

It is believed that the Schuler formation was deposited on an unstable shelf flanking the Gulf Coast basin and receiving a supply of clastics from the north and northeast. The North Louisiana Interior Salt Dome basin was separated from the East Texas basin by a shelf of less subsidence in the region of the Sabine uplift.

The marine sands of the Schuler formation were presumably deposited by longshore currents carrying clastics westward from a major delta in northeastern Louisiana and western Mississippi. Facies patterns developed on all the maps bear a definite relationship to the Cotton Valley producing trends in northern Louisiana.

[4] Read by title.

SYMPOSIUM ON FAUNAL FACIES AND THEIR LITHOLOGIC ASSOCIATIONS

April 14, 1:30 to 5:00 P.M.

Presiding: E. C. DAPPLES AND HEINZ LOWENSTAM

SOME MODERN FAUNAL AND LITHOLOGIC ASSOCIATIONS

FRED B. PHLEGER
Scripps Institution of Oceanography, La Jolla, California

This discussion is essentially confined to biofacies existing in areas of non-calcareous, detrital sediments. Foraminifera are emphasized because their ecology is best known, and any such group of variable organisms should illustrate principles.

Known depth distributions of benthonic Foraminifera show widespread boundaries at 100 m, 200 m, 500 m, and 2000 m, and larger invertebrates are believed to have similar bathymetric patterns although less is known about them. Nearshore distributions of both Foraminifera and macroorganisms in the Gulf of Mexico show a basic pattern of lagoon and open-ocean biofacies, and these can be further subdivided.

Depth biofacies of Foraminifera show only a very general relationship to sediment type where continental shelf, continental slope, and deep-sea sediments can be differentiated. Many nearshore facies of Foraminifera appear to be developed regardless of sediment type Exceptions are beaches, coral reefs, marine. marshes, and areas of rocky or stony bottom. Some facies of macroorganisms show a better relationship to sediment.

Correlation of faunas with sediment type has an ecologic significance in attached forms, coral reef associations, and burrowing types. it appears that mud-sand areas can support a very large population. In the southern Gulf of Maine an excellent correlation between biofacies and lithofacies is shown to be a coincidence. Where such correlation exists it is believed generally due to oceanographic factors which affect both sediments and organisms.

Mixing of foreign dead populations with an endemic living population may occur on a beach, in vertically displaced sediments such as from turbidity flows, and in areas of sediment deposited in a previous environment.

Submarine erosion of sediments containing fossil faunas also may be significant. Foraminifera populations do not appear to be transported significant distances in most environments except where masses of sediment also are transported. Problems in dealing with a population of planktonic organisms are discussed. Tentative principles of distribution of Foraminifera are enumerated; it is believed that these distribution principles apply to other groups of organisms which are potential fossils.

RELATIONSHIPS OF INVERTEBRATE ORGANISMS IN PENNSYLVANIAN STRATA

L. M. CLINE

University of Wisconsin, Madison, Wisconsin

This paper presents some of the results of some paleoecological studies of Pennsylvanian faunas of the Mid-Continent region. The project has been a group effort and several men who are now at or who have been at the University of Wisconsin have contributed significantly to the study; these include B. H. Burma, George A. Risely, Edward Heuer, Donald Lokke, Frank Brown, and David De Vries.

The cyclically arranged Pennsylvanian strata of the platform facies of the northern Mid-Continent are characterized by the rapid alternation of marine and non-marine beds, a large number of thin but laterally persistent rock units, and a diversity of rock types. This combination of lithologic features provides the type of control needed for paleoecologic studies. The simple cyclothem so characteristic of the Desmoinesian includes strata that ranged from fresh-water to marine environments and it embraces all of the common sedimentary rock types. The vertical interval from the coal upward to the marine limestone represents a gradual increase in depth and salinity of water that is reflected in gradual changes in faunas. Vertical changes are to some extent duplicated in individual members by lateral changes of a more regional nature. Virgilian strata in the Sacramento Range of New Mexico have a cyclic arrangement. The limestone members of some of the cyclothems show an upward gradation from thin-bedded fusulinid-bearing strata having a molluscoidean fauna into a massive algal biostrome cap, the gradation being interpreted as the result of gradually shoaling conditions. The vertical variation is repeated laterally as individual limestones are traced toward the ancient Pedernal landmass; the fusulinid-bearing strata grade shoreward into algal limestones which in turn eventually break down into a mass of calcareous nodules embedded in red shale.

RELATIONSHIP BETWEEN FAUNA AND LITHOLOGY IN THE MOENKOPI FORMATION[5]

EDWIN D. MCKEE

U. S. Geological Survey, Denver, Colorado

A close relationship exists between faunas and rock types in the Moenkopi formation of Triassic age in northern Arizona and southern Utah. This formation consists of marine sediments to the west, and continental sediments to the east and intermediate intertonguing.

Marine deposits consist of (1) limestone and (2) gray calcareous siltstone, that alternate to form seven or more cycles. The limestone, apparently developed in clear shallow waters, contains an abundance of crinoids, terebratulid brachiopods, a *Pugnoides*-like brachipod, and a few types of large pelecypods, notably *Aviculopecten*. Siltstone, formed as the shallow waters silted up intermittently, contains many species of small gastropods, and the crustacean *Halicyne*.

The continental deposits consist principally of (1) red shaly siltstone of mud-flat origin, (2) red structureless mudstone, formed in bodies of quiet water, and (3) thick-bedded sandstone deposited in stream channels. Abundant reptilian footprints and some reptile bones constitute the faunal record of the mud flats; no fossils are found in the red mudstone; skulls, and other bones of large amphibians, and a few amphibian tracks are present in the stream deposits.

Other environments of the Moenkopi include lagoons, indicated by deposits of gypsum, and fresh- or brackish-water ponds, represented by pelecypod- or fish-bearing limestones. Intraformational conglomerates, some containing mud and clay pellets—others limestone pebbles—are numerous but local. Many of them contain accumulations of water-worn bones of vertebrate animals.

A QUANTITATIVE LITHOFACIES AND BIOFACIES STUDY OF THE FLORENA SHALE (PERMIAN) OF KANSAS

JOHN IMBRIE

Columbia University, New York, New York

The purpose of this study is to test the practicality and scientific potential of an analytical technique designed to produce quantitative data on biofacies and lithofacies changes. The unit selected for analysis is the Florena shale member of the Beattie limestone (Wolfcampian), a fossiliferous unit

[5] Published with permission of The Director, U. S. Geological Survey.

traceable across Kansas from Nebraska to Oklahoma.

Seventeen complete sections of the Florena, spaced as evenly as possible over the belt of outcrop, were studied. In addition to field procedure usual in biostratigraphic work, trench samples were taken, each sample totaling eleven pounds and representing no more than one foot of section. One pound of each sample was saved for lithologic analysis. The remaining ten pounds were disaggregated and sieved, selected fractions being separated into fossil and non-fossil portions. The fossil portion, comprising whole specimens and fragments, was separated into taxonomic groups and each group weighed.

These weights provide an accurate estimate of the abundance of the taxonomic category in the sample. Although such a measure is of little value by itself, systematic changes in fossil abundances of samples taken at different stratigraphic and geographic positions may be highly significant.

It is obvious that a complex of factors, random and non-random, primary and secondary, will affect fossil abundance. In the Florena shale, however, the abundance of many groups of fossils shows systematic geographic and stratigraphic variations; and it is therefore probable that (in this case) non-random changes are being measured. Petrographic and chemical analyses of the same samples also show systematic lithologic changes. Paleontologic and lithologic data can thus be conveniently compared and facies relationships precisely and objectively formulated. The documentation of these relationships, in turn, provides a sound basis for hypotheses of primary (ecologic or evolutionary) and secondary (diagenetic) control.

SAMPLE-POPULATION CONCEPTS IN FAUNAL-LITHOLOGIC FACIES STUDIES

ROBERT L. MILLER AND EVERETT C. OLSON
Univesity of Chicago, Chicago, Illinois

Whenever collections are made in the field it should be recognized that a sampling procedure is involved. That is, the geologist wishes to draw inferences about a much larger aggregate on the basis of the sample he has drawn. In general, inferences may be drawn from a sample with or without the aid of statistical methods. In either case a fundamental consideration is involved. It is to determine the nature of the population or universe from which the sample is drawn.

In this talk the authors focus their attention on the relations between studies of ancient and modern environments. The discussion is in terms of sample vs. population in order to facilitate a theoretical examination of some applications of statistics to various aspects of environmental studies.

Particular attention is paid to the following:

1. The use of modern studies to construct models for use in studies of ancient environments.
2. The concept of key measures and key patterns involving both fauna and lithology.
3. A quantitative model, as an alternative approach to the facies concept.

SYMPOSIUM ON REGIONAL ASPECTS OF CARBONATE DEPOSITION

April 15, 9:00 to 12:00 A.M.

Presiding: DAN FERAY AND FRANK E. LOZO, JR.

THE DISTRIBUTION OF MARINE CARBONATE SEDIMENTS

JOHN RODGERS
Yale University, New Haven, Connecticut

Modern marine carbonate sediments may be roughly grouped into three main classes: Deep-water oozes, organic ("coral") reefs and associated deposits, and continental shelf lime-sands and lime-muds; the last two overlap somewhat.

Carbonate ooze covers vast areas on the bottoms of the three great oceans, especially in low latitudes and where the water is less than 3 miles deep. Tests of pelagic foraminifers are the principal component of at least the purer oozes, though pteropod shells and coccoliths are locally important. Clayey carbonate ooze occurs in somewhat deeper water and also toward coasts where there is much terrigenous sediment; it is common in the deeper basins of the world's mediterraneans. Such ooze probably did not form before the Cretaceous; the accessible geologic record apparently contains nothing like the ooze of the open ocean but may contain deposits like those in the modern mediterraneans.

Organic reefs are practically confined to low latitudes; atolls dot the open oceans but

the largest reef areas are on continental margins, as in the East and West Indies. Here the reef deposits are associated with wide areas of shelf carbonate deposits, chiefly fragmental-organic, but with chemical deposits locally. Deposits of this type, with local areas of reefs, have been common since the Middle Ordovician on shelves and in epeiric seas; before that chemical precipitation probably played a relatively more important part. In general shallow-water carbonate deposits seem to have been more common during the late Precambrian, Paleozoic, and Mesozoic than during the Cenozoic or today.

CALCIUM CARBONATE DEPOSITS OF THE GREAT BAHAMA BANK, BRITISH WEST INDIES

NORMAN D. NEWELL AND J. KEITH RIGBY[6]

American Museum of Natural History and Columbia University, New York, New York

Southeast of Florida the continental shelf forms an enormous limestone plain of which nearly 60,000 square miles has a mean relief of about 30 or 40 feet. This is the Bahama Plateau, much of which is barely awash at low tide. Conditions of sedimentation here must closely resemble those responsible for many of the limestone deposits so characteristic of Paleozoic and Mesozoic shelf seas. Nearly three miles of pure carbonate deposits were laid down in the Bahamas during the Cenozoic era, indicating very high average rates of deposition limited probably only by the rate of subsidence.

The Bahamas are bathed by the warm Antillean Current on the northeast and by the Florida Current on the west. Both streams continually bring great quantities of calcium carbonate to the shallow banks. The main bank and separate outliers are all rimmed by coral reefs and low islands thrown up by waves and wind; the highest and most extensive areas of elevated rim lie on the windward, eastern side of each bank. Comparatively fine sediments are trapped and deposited in the shallow central basins of the banks. Dominantly organic sediments—coral reefs and reef detritus—are being produced around the rim of each bank whereas chemical precipitates in the form of calcareous ooze and oolite sand are the principal sediments being formed within tide bank areas.

The plateau is bounded by very steep slopes that extend to great depths, comparable with those of oceanic coral atolls, and, as with the latter, suggestive of nearly vertical reef growth during subsidence, modified, doubtless, by wave action during low sea levels.

[6] Presented by Walter H. Bucher, Columbia University, New York, New York.

EARLY DIAGENSIS AND LITHIFICATION OF CARBONATE SEDIMENTS IN SOUTH FLORIDA

ROBERT N. GINSBURG

University of Miami Marine Laboratory, Coral Gables, Florida

Diagenesis and lithification include processes which convert sediment into rock. They are of special importance to the study of limestones because of the ease with which they modify the texture, structure, and composition of carbonate sediments. The intense physical, chemical, and biological processes which operate during deposition and within the first few feet of burial comprise Early Diagenesis. Subsequent processes are of longer duration and less intensity. Grain size and related properties exercise some control on the rate and extent of diagenesis in both phases.

Physico-chemical precipitation of calcium carbonate in the shallow tropical seas occurs under extreme conditions of temperature, salinity, and nucleation. It may also take place within submarine sediments, but apparently not as a lithifying cement. Petrographic comparison of lithification of the Late Pleistocene Miami Oolite with that of the Mississippian Fredonia Oolite suggests that cementation in both cases was accomplished only after removal from the marine environment. Unlithified carbonate sediments found well below the surface on some Pacific atolls support this view.

MISSISSIPPIAN CARBONATE DEPOSITS OF THE OZARK REGION

RAYMOND C. MOORE

University of Kansas, Lawrence, Kansas

Rocks of the Mississippian System, which originally covered all of the Ozark region in Missouri and adjacent states, consist mainly of carbonate deposits. Study of the nearly continuous outcrops of Mississippian formations now found on the flanks of the Ozark dome leads to recognition of several distinct types of carbonate rocks and permits determination of their regional stratigraphic relations. The wide-spread occurrence of siliceous sediment in the form of chert nodules and beds is an outstanding peculiarity of some formations, whereas chert is virtually unknown in others. This dissimilarity and the observation that chert associated with various stratigraphically distinguishable parts of the Mississippian deposits in this region are features which cannot be ignored in research on the nature of sedimentation that produced the carbonate rocks. Most of the differences are primary.

Data and conclusions given in the present paper are based largely on field work undertaken in 1953 for the purpose of lithologic sampling but they embrace also extensive previous acquaintance with the rocks discussed.

GENERAL PALEONTOLOGY AND STRATIGRAPHY

April 15, 1:45 to 5:00 P.M.

Presiding: F. M. SWAIN AND ALLEN F. AGNEW

BRAZILIAN DEVONIAN CARPOIDS

KENNETH E. CASTER

University of Cincinnati,
Cincinnati, Ohio

Two new genera of carpoid echinoderms from the Ponta Grossa (Devonian) shale of Parana, Brazil, are described. These are the first carpoid echinoderms to be reported from South America, and the second occurrence in the Southern Hemisphere, three specimens from the Union of South Africa being the only previous discoveries, and in beds of the same age as the Ponta Grossa shale.

The Brazilian forms are of two distinct lineages, one of the placocystoid general organization, the other recalling somewhat in its exceptional asymmetry the lagynocystids of Europe. The Brazilian fossils are quite distinct from the placocystoid forms from South Africa, a revision of which is also undertaken in the present study.

These new organisms serve to epitomize the paleogeographic isolation of Afro-Brazilian faunas in Lower Devonian times, and the highly autochthonous aspect of the fauna.

LITHOLOGIC AND FAUNAL CHARACTERISTICS OF LOWER CRETACEOUS AND PRE-CRETACEOUS (?) LIMESTONES OF SOUTH PENINSULAR FLORIDA[7]

P. L. AND E. R. APPLIN

U. S. Geological Survey,
Jackson, Mississippi

A thickness of more than 5,000 feet of carbonate rocks and evaporites of early Cretaceous and Jurassic? age consitutes the larger part of the subsurface stratigraphic section near the south end of the Florida peninsula. Relations between the Lower Cretaceous units in Florida and units of equivalent age in Mexico and Texas are discussed and correlations suggested. A possible Jurassic age is suggested for the limestone and dolomite penetrated in the basal part of two wells in south Florida. Twenty-four photomicrographs of thin sections of the carbonate rocks demonstrate characteristic lighologic and microfaunal features of the Lower Cretaceous and Jurassic? units, and four plates show diagnostic microfossils.

[7] Published by permission of the Director, U. S. Geological Survey.

RECENT OSTRACOD BIOFACIES IN EAST MISSISSIPPI AREA[8]

DORIS MALKIN CURTIS

La Jolla, California

Ostracoda were studied from Recent samples collected in the East Mississippi Delta Area as part of A. P. I. Project 51 (Study of Recent Nearshore Sediments in the Gulf of Mexico). Frequency distribution of the species in this area indicates that several distinct environments can be recognized by their characteristic ostracod assemblages. The three principal biofacies in the area are (1) marsh facies, (2) Breton Sound facies, and (3) open Gulf facies. A zone of mixing connects the open Gulf and Breton Sound facies.

The marsh biofacies is characterized by extremely rare individuals and species, generally fresh to brackish water types.

The Breton Sound biofacies may be divided into:

(a) *Inner Breton Sound subfacies*, characterized by the presence of numerous individuals belonging to relatively few ostracod species, including *Trachyleberis* cf. *exanthemata*, *Hemicythere* sp., *Perissocytheridea* spp., *Cytherura* spp., *Microcythere* sp., *Candona* sp.

(b) *Breton Sound subfacies*, characterized by the presence of numerous individuals in relatively few ostracod species, including *Perissocytheridea* spp., *Cytherura* spp., *Loxoconcha* spp., *Leptocythere* sp., *Microcythere* sp., *"Cytheridea"* sp., *Cytherideis* spp.

Most species of the Breton Sound facies are found in the mixing zone.

The open Gulf biofacies may be divided into:

(a) *Nearshore subfacies* (in area of prodelta clays and silts), characterized by relatively rare individuals and few species, including *Favella* cf. *rugipunctata*, *Cythereis echinata*, *Pellucistoma* sp., *Cytherideis* spp., *Cytheretta* sp., *Microcythere* sp. The species of this subfacies are found in the mixing zone.

(b) *Offshore subfacies* (in area of offshore clays), characterized by abundant individuals of many species, including *Trachyleberis* sp., *Favella* cf. *rugipunctata*, *Cythereis echinata*, *C.* cf. *margaretifera*, *Pellucistoma* sp., *Cytheridea* sp., *Cytheretta* sp., *Pterygocythereis* sp., *Hemicythere* sp., *Krithe* aff. *bartonensis*, (?) *Macrocytherina* sp., *Cytheropteron* sp., *Brachycythere* sp., *Cytherella* sp., *Cytherelloidea* sp., etc.

[8] This investigation was supported by a grant from the American Petroleum Institute, Project 51.

POST-GLACIAL STRATIGRAPHY ALONG THE CENTRAL TEXAS COAST[9]

F. P. Shepard and D. G. Moore
Scripps Institution of Oceanography, La Jolla, California

Twenty holes with an average depth of 55 feet were drilled into the barrier islands, bay floors, and into a bay head delta in the Rockport-Aransas Pass area of the Texas coast. The extensive criteria developed previously for recognition of depositional environments in this area were used to interpret the drill samples. These borings, which were mostly a combination of three feet washing and two feet coring, indicate a general uniformity of conditions during the several thousand years which are believed to have followed the last major rise in sea level at the end of the Pleistocene. In Lower San Antonio Bay a section of 80 feet was penetrated before reaching the base of bay deposits similar to those of lower bays of the present day; whereas under the Guadalupe Delta a section of 50 feet was crossed before getting below deposits characteristic of upper or middle bay conditions. Under the gulf beach of Saint Joseph Island the drill penetrated 65 feet before getting out of formations characteristic of various parts of the present barrier islands including beaches, dunes, and inlets. In middle San Antonio Bay, where oyster reefs form numerous shoals at the present time, a thickness up to 50 feet of oyster reef material was traversed in getting below the bay deposits.

There are many problems arising from the study of the cores which are proving difficult to explain without more extensive drilling. However, the indications from the available material are that either the area has been sinking with deposition keeping pace since the return of the sea at the end of the glacial period, supposedly some 6,000 years ago, or that the deposits were formed at least in parts as the sea level rose. Deposition of the entire section during rise in sea level seems unlikely because of the long interval since the return of the sea and because bay deposition is now occurring at rates in excess of one foot per century. In any case it seems likely that barrier island sands can develop considerable thicknesses between the silts and clays of the bays on one side and of the open continental shelf deposits on the other resulting, after burial, in the production of stratigraphic traps for future petroleum.

[9] This investigation was supported by a grant from the American Petroleum Institute, Project 51.

NON-MARINE FRONTIER MICROFAUNA, COALVILLE AREA, UTAH

Daniel J. Jones
University of Utah, Salt Lake City, Utah

Foraminifera and marine Ostracoda have been previously described in the Coalville Area of northeastern Utah. However, recent work in the area has demonstrated the existence of 10 feet of fossiliferous non-marine strata in the lower portion of the Frontier a few miles southwest of good exposures of the marine section. Several species of Charophyta and non-marine Ostracoda are described and illustrated. It is inferred from the microfossil evidence that the non-marine facies represents flowing of continental sediments into lagoonal or marginal areas of the Frontier sea from nearby positive elements of the Wasatch and Uinta uplifts.

A CRETACEOUS VERTEBRATE FAUNA OF MINNESOTA AND SOUTH DAKOTA

Robert E. Sloan
University of Minnesota, Minneapolis, Minnesota

A thin arkosic conglomerate rests directly on top of an Archean gneissic granite in a series of outcrops and quarries along the southern edge of the Minnesota River valley in Grant County, South Dakota and Lac qui Parle County, Minnesota. It is probably to be correlated with the Benton group, possibly with the Graneros formation. Elements of the fauna present include a specis of *Ichthyodectes;* Toxochelid and Protostegid turtles, a Ptychodont and several sharks. In addition carbonized wood from a gymnosperm is present. The conglomerate is apparently part of the overlapping sequence of upper Cretaceous sediments and represents a near shore environment.

SOME FORAMINIFERA, RADIOLARIA AND OSTRACODA FROM THE CRETACEOUS OF MINNESOTA

Edward J. Bolin
State Geological Survey, Vermillion, South Dakota

Two microfaunas consisting of twenty-one species of Foraminifera, one of Ostracoda, and three of Radiolaria are described and illustrated from the Cretaceous of Minnesota.

Outcrop samples from Lyon and Redwood counties yielded a fauna including eleven species of calcareous Foraminifera, one ostacode of the genus *Cythereis*, and three species of nasselariad radiolaria. The eleven species

of Foraminifera, representing the genera *Gumbelina, Loxostoma, Globigerina, Globigerinella, Gyroidina, Neobulimina, Planulina,* and *Anomalina,* suggest that these sediments are the age equivalent of the Niobrara formation.

A foraminiferal fauna consisting of one calcareous and nine arenaceous species was encountered in the Coleraine formation from drill holes between the Mesabi and Cuyuna iron ranges, in Aitkin and Crow Wing counties. The calcareous species, *Globigerina washitensis* Carsey, was represented only by two glauconitized specimens. The nine arenaceous species, representing *Ammobaculites, Ammobaculoides, Haplophragmoides,* and *Trochammina,* are described as new. The nature of the fauna suggests a near shore, cold, and probably brackish water environment.

THE ISOLATION AND CULTIVATION OF MICRO-ORGANISMS FROM DEEP WELL BORINGS IN THE WILLISTON BASIN

JAMES M. WILLIAMS, WILLARD D. PYE, AND CASPER I. NELSON

Departments of Geology and Bacteriology, North Dakota Agricultural College, Fargo, North Dakota

As part of a continuing research program dealing with various geological problems of the Williston Basin, a project was undertaken to determine the physical properties of the brines produced from wells drilled within the Basin.

Samples of fluids were secured from two wells in the Beaver Lodge, North Dakota, field and one sample each from the Richey and Pine Unit, Montana, fields, and one from a wildcat dry hole in Bottineau County, North Dakota. Fluids were from Mississippian formations at depths of 7000–8000 feet.

The organisms examined were anaerobic. Aerobic bacteria, if present in the fluid, were not studied as they could have resulted from contamination. Tests were made for contamination and media were used which would not support most of the contaminants. The anaerobic bacteria were best isolated from the brines rather than the oil fractions of the fluid.

An environment of pure nitrogen proved to be most suitable for the initial isolations, and a temperature of 45°C. was the most satisfactory. The most successful growing medium consisted of 2% yeast extract (Difco), 0.2% NH_4Cl, 0.2% $NaNO_3$, 0.2% Na_2SO_3 and water. After the medium was sterilized, a 1% solution of ferric sulphate was added aseptically. The final pH was 7.0. Reduced methylene blue was used as an indicator of anaerobiosis.

After preliminary isolations were made, it was found that fluid Thioglycollate Medium (BBL) could be used in an anaerobic environment. After considerable cultivation, the optimum temperature for incubation could be reduced to 30°C.

Five different types of organisms were isolated. Of the organisms isolated one proved to be *Desulfovibrio* sp. (probably *D. desulfuricaus*), three appear to belong to the Clostridium group and one has yet to be identified.

Desulfovibrio sp. rapidly reduced a 1% solution of ferric sulphate to ferrous sulfide. The organisms rapidly died out when the cultures were exposed to atmospheric oxygen. All of the isolated organisms attacked various carbohydrates to form various organic acids and in some instances gases. All but the form *Desulfovibrio* sp. will eventually reduce the carbohydrate acid to neutral compounds. These same bacteria will attack the protein casein, with the production of an acid coagulation of the proteins followed by a digestion of the coagulated substances. All but one of the organisms, exclusive of *Desulfovibrio* sp., exhibit proteolytic activity by liquefying gelatin. These reactions are accompanied by the release of carbon dioxide and hydrogen sulfide. Some of these isolates are capable of nitrate reduction, which could account for the presence of nitrites in the brine samples.

The geological significance is that the isolated bacteria not only are capable of attacking and reducing carbohydrate and protein material to possible precursors of petroleum but in so doing release various gases characteristic of oil fields and the organic and inorganic acids which they produce are capable of attacking carbonates thus developing porosity and liberating absorbed oil.

DISTRIBUTION OF MARINE UPPER JURASSIC OSTRACODES, WESTERN INTERIOR UNITED STATES

JAMES A. PETERSON

Shell Oil Company, Salt Lake City, Utah

Micropaleontologic studies indicate the presence of two distinct ostracode biofacies in the Rierdon formation and equivalent rocks in Montana and Wyoming, whereas only a single ostracode zone is present in the overlying Swift formation and equivalent rocks of the same area. Distribution of the two Rierdon assemblages was apparently governed by the presence of an east-west arch (the "Sheridan Arch") across north central Wyoming and southeastern Montana during at least the early part of Upper Jurassic time. The zone found in the Swift formation contains an ostracode assemblage closely related to that present southeast of the Sheridan Arch during Rierdon deposition, but the forms present in the Rierdon northwest of the arch have not been found in the Swift and equivalent rocks.

These facts, in conjunction with stratigraphic data, imply several conclusions regarding Upper Jurassic paleogeography and may provide additional clues regarding the changing sedimentary and paleogeographic picture during the transition period between the fading out of the Paleozoic Cordilleran Geosyncline and the beginning of the trough system which dominated Western Interior sedimentation during the middle and late Mesozoic Era.

PALEOZOIC FOSSILS IN CRETACEOUS CONGLOMERATES FROM COLORADO

JOHN CHRONIC
University of Colorado, Boulder, Colorado

Well preserved, silicified, invertebrate fossils of Late Paleozoic age have been found in basal Cretaceous conglomerates, along the Front Range and in North Park, Colorado. Fusulinids, sponge spicules, corals, brachiopods, bryozoans, mollusks, and echinoderms have been recognized. Specimens occur in rounded chert and silicified sandstone pebbles up to approximately two inches in diameter.

Apparent uniformity of fauna in the pebbles over a considerable area, and their abundance in most sections in the area, indicate an extensive supply of Paleozoic sediments at the beginning of Cretaceous deposition.

Three sources for the pebbles seem possible:

1. They may have been weathered from Morrison or pre-Morrison conglomerates during early Cretaceous time, and redeposited without appreciable transportation.
2. They may have been eroded from some original source in the region, through a 'hole' or 'holes' in the Morrison formation, and distributed by fluvial or marine processes which deposited the basal part of the Dakota group.
3. They may have been eroded from some original source outside the area covered by the Morrison formation, and carried into their present site by fluvial and/or marine agencies.

Bryozoans dominate in the pebbles; mollusks are rare and poorly preserved. Ecologically, this relationship suggests that the original fossil-bearing sediments were deposited in relatively quiet, clear, marine waters at a considerable distance from shore.

LATE MISSISSIPPIAN-EARLY PENNSYLVANIAN OF SOUTHERN MIDCONTINENT

MAXIM K. ELIAS
University of Nebraska, Lincoln, Nebraska

Intensive field investigations in south-central Oklahoma conducted in the last decade by several geologists resulted in rediscovery of old and discovery of many new fossil localities in the late Mississippian and early Pennsylvanian formations. The study of the fossils collected by them and by me, together with subsequent additional field work, resulted in considerable modification of our understanding of the local stratigraphy and correlations, particularly of the Caney, Springer and Morrow. Conodonts, goniatites, and also some other mollusks, ostracodes and brachiopods have restricted stratigraphic range, and the established succession of the goniatites allows close correlation with the corresponding zones of Britain and western Europe. The zones involved are the Namurian (E, H, and R), and the lower Westphalian (G).

LITHOLOGIC FEATURES OF CORES OF JURASSIC LIMESTONE FROM A DEEP WELL IN SOUTH MISSISSIPPI[10]

P. L. AND E. R. APPLIN
U. S. Geological Survey, Jackson, Mississippi

Fourteen photomicrographs of thin sections show distinctive lithologic features of a series of cores of limestone of Jurassic age from depths of about 19,000 to 20,000 feet in the George Vasen Fee well 1, Stone County, Miss.

A PALEOECOLOGICAL STUDY OF THE VIESCA MEMBER OF THE WECHES FORMATION, SMITHVILLE, TEXAS[11]

NEVILLE M. CURTIS, JR.
Department of Geology, Marietta College, Marietta, Ohio

Interpretation of the environment in which the Viesca member of the Weches formation at Smithville, Texas was deposited is based on three lines of evidence: (1) regional tectonic framework during Weches time; (2) sedimentary characteristics of the Weches formation at Smithville and other localities; and (3) variations in percentage of foraminiferal species throughout the Viesca section of the Weches at Smithville.

The source area for the Viesca sediments is considered to have been the Llano uplift area, with the Colorado River transporting the majority of the sediments. The age of the source rocks is considered to be no older than Edwards and no younger than Viesca. The Llano uplift area is thought to have been stable to mildly epeirogenic during Viesca time.

The rate of deposition (slow), chemical stability of water, degree of tectonic activity (stable) in the depositional area, are based on the glauconite, which is found in great abundance throughout the Viesca member.

Interpretations based on the relationship

[10] Published with permission of the Director, U. S. Geological Survey.

[11] Read by title.

(variations in frequency percentage) between *Siphonina claibornensis* and *Quinqueloculina claiborniana* show that during Viesca deposition there was oscillation of sea level in the Smithville area. Water depths ranged from 3 feet to approximately 100 meters. The section is divided into four depth zones: 0–40 meters, 30–50 meters, 50–80 meters, and 80–100 meters.

The salinity (16.5–35%) or chlorinity (10.0–19.0%) interpretations are based on the presence of the oyster "bank" in the Viesca member. The temperature (14° C.), pH of water (approximately 8.2), and turbidity of water (low) are also interpreted from the oyster bank.

Environmental analysis by means of Foraminifera is supported and supplemented by other lines of evidence. It is possible to reconstruct environment from a single short (10 foot) section, but regional studies are necessary for a complete picture.

ABSTRACTS OF PAPERS
1953 ANNUAL MEETING, PACIFIC COAST SECTION SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

The 1953 Annual Meeting of the Pacific Coast Section of the Society of Economic Paleontologists and Mineralogists was held in Los Angeles, California, on November 5 and 6. Some of the sessions were held jointly with the American Association of Petroleum Geologists and the Society of Economic Geologists but the abstracts of these papers are not included.

Pacific Coast Section officers for the year 1953–1954 are as follows:
President: JOHN W. RUTH, Standard Oil Company, Los Angeles, California
Secretary-Treasurer: WAYNE ELLIOTT, Richfield Oil Corporation, Long Beach, California

ANNUAL DINNER AND EVENING SESSION
November 5, 7:00 P.M.

Presiding: ORVILLE L. BANDY AND DANA D. BRAISLIN, JR.

CLASSIFICATION OF SPORES AND POLLEN FOR PALEONTOLOGIC CORRELATION

W. L. NOREM
California Research Corporation,
La Habra, California

One of the more important recent developments in micropaleontology is the use of plant spores and pollen for correlation purposes. These minute bodies are found in many sediments previously considered barren of diagnostic fossils. The classification of spores and pollen presents a complex problem because of the large number of types that represent almost every phylum of the plant kingdom and cover the geological time span from the Paleozoic to the present.

Classification under the International Rules of Botanical Nomenclature is confusing because materials of known affinities are classified according to phylogenetic relationships and those of unknown parentage according to morphological characteristics. No clear cut distinction is made in the nomenclature between fossils classified in the natural and the artificial systems. A natural system is not necessarily the most satisfactory for the stratigraphic paleontologist because of the vast knowledge of systematic botany required for its application.

If fossil spores and pollen are to be brought quickly into usefulness for paleontologic correlation, a system of classification that is easy to use must be developed. Such a system must have a minimum possibility for confusion in its application. It must be comprehensive enough to cover all spore types from the Paleozoic to the present. It should contain the elements of a key for quick and easy reference. Like the International Rules of Botanical Nomenclature, its use should be universal so as to

permit the free interchange of information on spores and pollen.

The classification based on morphological characteristics and proposed by G. Erdtman contains the elements of such a system. It must, however, be expanded in scope before it will be complete.

This artificial system is not intended to replace the natural system under the International Rules in paleobotany but it is intended as a practical substitute for use in stratigraphic paleontology. The fossil spores or pollen can be reclassified under the natural system when and if the affinities are ascertained.

GENERAL SESSION

November 6, 9:30 to 12:00 A.M.

Presiding: R. STANLEY BECK AND J. D. BAINTON

SIZE DISTRIBUTION OF GRAVELS

K. O. EMERY

University of Southern California, Los Angeles, California

More than 60 samples of gravel from beaches of Mexico and southern California were mechanically analyzed in the field using a new method. Median diameters range between 20 and 800 mm. Trask sorting coefficients are characteristically lower than 1.5 and have a median of 1.25. Comparison with published analyses shows that the marine beach gravels are far better sorted than gravels from streams and alluvial fans. The difference is sufficiently great that sorting may be a useful supplementary means of determining the environment in which ancient conglomerates were deposited.

EOCENE FORAMINIFERA FROM THE WOODSIDE DISTRICT, SAN MATEO COUNTY, CALIFORNIA

JOSEPH J. GRAHAM

Stanford University, Palo Alto, California

An Eocene foraminiferal assemblage from the Woodside district near Redwood City, San Mateo County, California, is described and its similarity to Cushman and Siegfus' Canoas siltstone faunule from the type area of the Kreyenhagen shale of California noted.

RECOGNITION OF PLAYA SEDIMENTS IN THE GEOLOGIC COLUMN

RICHARD STONE

University of Southern California, Los Angeles, California

Playa sediments are sometimes reported in oil well cuttings, particularly in sediments whose age is Miocene or younger. A careful investigation of the sedimentary properties of playa sediments of the present has revealed certain characteristics which it is believed will enable the geologist to definitely recognize older sediments which were deposited in the playa environment. These diagnostic properties include the average grain size, sorting coefficient, color, organic carbon content, alkali and salt content, hydrogen ion concentration, and the oxidation-reduction potential. In playa sediments most of these properties have rather definite ranges. This makes it possible to recognize playa sediments with a greater degree of certainty.

GENESIS OF PELAGIC SEDIMENTS

GUSTAF ARRHENIUS

Assistant Research Oceanographer, Scripps Institution of Oceanography, La Jolla, California; Visiting Research Fellow, California Institute of Technology, Pasadena, California

The pelagic sediments form polydisperse systems where the liquid phase is the interstitial water, and the solid phase is built up by several genetically different components. In E. D. Goldberg's genetical system these are grouped according to the geological sphere in which the solid phase was separated. The solids are thus classified as lithogenous, hydrogenous, biogenous, atmogenous, cosmogenous, and authigenous. Modern analytical methods make it possible to determine quantitatively the concentrations, and in ideal cases the rates of accumulation of these components.

SOME SPECTACULAR EFFECTS OF WIND EROSION NEAR PALM SPRINGS, CALIFORNIA

THOMAS CLEMENTS, JOHN F. MANN, JR., RICHARD O. STONE, AND JAMES L. EYMANN

University of Southern California, Los Angeles, California

A short distance northwest of Palm Springs, California, a climbing dune has been formed in a gap in a spur of the San Jacinto Mountains that extends easterly into Coachella Valley. Wind funnelling through the pass be-

tween the San Jacinto and the San Bernardino Mountains picks up sand from the dry wash at the base of the spur and carries it up through the gap. The sand is coarse and the wind is almost constant, as a result of which spectacular wind effects have been achieved.

Juniper trees that have managed to grow at all have been bent over until the trunks have broken, and they are now growing in a prone position, with smaller plants crowding closely in their lee. Small plants also cluster in the lee of the larger projecting rocks, growing laterally rather than vertically. These rocks, which are principally granitic, with some gneiss, schist, and quartzite, are pitted, grooved, and fluted in a most fantastic way. More fantastic still, however, is the fact that the grooving and fluting is continued without variation in the bushes sheltering behind the rocks.

SOME GUIDE FORAMINIFERA OF THE UPPER CRETACEOUS AND LOWER TERTIARY IN AUSTRALIA AND CALIFORNIA

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A number of stratigraphically restricted species of Foraminifera are found in the late Cretaceous and early Tertiary of Australia and California. These cosmopolitan species are also found in many other parts of the world, often under different names. They have been noted in samples collected here for the Richfield Oil Corporation and for the Bureau of Mineral Resources in northwest Australia. Their identification permits direct or indirect correlation with standard European stages and thus contributes to a universal stratigraphy, as well as to the knowledge of paleogeography. In addition, the widespread occurrence of index Foraminifera for the Maastrichtian and Danian-Paleocene often permits an exact distinction between uppermost Cretaceous and lowermost Tertiary.

CALIFORNIA LOWER TERTIARY FORAMINIFERAL SEQUENCE

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A preliminary statement of the formal names proposed for the major divisions and subdivisions of a chronologic-biostratigraphic classification of the California Lower Tertiary, and a summary of the criteria upon which each of these is based will be presented in this paper.

Evaluation of the faunal changes found in a complete stratigraphic sequence of foraminiferal faunas in the California Province has shown that this sequence of faunas resolves itself into six distinct major units of Stage magnitude which are differentiable throughout the California Province, and several units of Zonal magnitude which subdivide the Stagial units based upon the joint occurrences of species of Foraminifera.

The major subdivisions of the Paleocene are the Ynezian and Bulitan Stages constituting the oldest and next oldest Stages of the Tertiary. The Eocene subdivisions are the Juniperan Stage, Lower Eocene; the Middle Eocene Ulatisian Stage; and the two Upper Eocene Stages, the oldest, the Narizian, and the youngest, the Fresnian Stage.

The Zonal subdivisions of these Lower Tertiary Stages of the California Province are the *Silicosignoilina californica* and *Bulimina excavata* Zones of the Ynezian Stage; the *Bulimina bradburyi* and *Valvulineria wilcoxensis* Zones of the Bulitan Stage; the *Plectofrondicularia kerni* and *Alabamina wilcoxensis* Zones of the Juniperan Stage: the Ulatisian Stage with three distinct Zones, only one of which, the uppermost Zone, the *Amphimorphina californica* Zone is named; the *Uvigerina churchi* and *Uvigerina garzaensis* Zones of the Narizian Stage; at least two Zones exist within the Fresnian Stage, but these are not named at the present time.

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Announcements

NATIONAL CLAY MINERALS CONFERENCE

Clay Mineral Technology is the theme of the Third National Clay Minerals Conference to be held at the Rice Institute, Houston, Texas, October 27, 28, 29, 1954. The conference is sponsored by the Clay Minerals Committee of the National Research Council. A special part of the program will be devoted to fundamental or applied papers. Anyone interested in presenting papers in *any* of these or *other* fields pertaining to clays or related minerals is invited to announce their intentions to A. F. Frederickson, Washington University, St. Louis 5, Missouri, on or before July 15, 1954.

A detailed program, including field-trip information, will be available on request in August, 1954. *Everyone* interested in any aspect of clay mineralogy, technology or related fields is cordially invited to attend the Conference.

INTERNATIONAL ASSOCIATION OF SEDIMENTOLOGY

On the eleventh of September 1952, at two-thirty P.M. at the Nineteenth International Geological Congress in Algiers a reunion was held for the purpose of officially founding an International Association of Sedimentology, based on the principles that had already been accepted at the Third Congress of Sedimentology at Wageningen in 1951. The resolutions were voted, and a board was nominated.

The Association bears the name International Association of Sedimentology. The aims of the Association are to promote the studies of sedimentology; to undertake the necessary steps to aid and coordinate the research in all the branches which demand international cooperation; and to furnish the possibilities for discussions, the comparison, and the publication of the results of the research.

The Association is open to all workers interested in the study of sedimentology and sedimentary rocks. Workers in other sciences can be invited as guests to the meetings if their papers are closely related to sedimentology.

The board is as follows:

President: Dr. D. J. DOEGLAS, Landbouwhogeschool Geologie, Duivendaalse laan 2, Wageningen, The Netherlands.
Vice-President: Dr. C. W. CORRENS, Sedimentpetrographisches Institut der Universität, Göttingen, Germany.
General Secretary and Treasurer: Dr. A. VATAN, Institut Française du Pétrole, Rueil Seine et Oise, France.

A fee of one dollar will be asked each year from each member. This fee is to be sent to:

Association Internationale Sedimentologie
Institute Français du Pétrole
4 Place Bir Hacheim, Rueil Malmaison S. et Oise
C.C.P. Paris, 10972–93 France

Temporarily in Indonesia Dr. D. J. DOEGLAS has announced that he can no longer assume the presidency, which is provisionally taken by Prof. C. W. CORRENS.

The board desires to receive suggestions concerning the way in which the Association can realize its aim.

The secretariat is working on the establishment of a list of sedimentologists as well as of the subjects they study. This list already exists in part. The authors are invited to send to the secretariat a list of their works.

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REVIEWS

The Literature of Geology by Brian Mason, 1st ed., 1953. Pp. vii+155; 5½×8½ ins., paper. By the author at the American Museum of Natural History, New York 24, New York. Price, $2.00.

This unassuming little book, little larger than Howell and Leversen's *Directory of Geological Material in North America* (1946) and much smaller than Pearl's *Guide to Geologic Literature* (1951) does its carefully limited job very satisfactorily.

Part I includes divisions on abstracts, bibliographies, biographies, directories, glossaries, and special fields of geology. Prat II is divided into geographic areas of the world; the separate continents are sub-divided into states and counties. An appendix lists International Congress publications.

Mason's book supplements rather than duplicates Pearl's. Pearl's book deals extensively with bibliographic techniques and gives leads into "fringe" subjects, while Mason's book confines itself to listing important publications in geology in an easily manipulated classification. Mason's book will be very useful to students and professional geologists; those in charge of maintaining and developing geological libraries will particularly welcome it.

GEORGE W. WHITE
University of Illinois

Deep Sea Research edited by L. Fage (Paris), Cameron D. Ovey (Cambridge), Mary Sears (Woods Hole, Mass.) vol. 1, no. 1, 1953. Pp. 64; 6¾×10 ins. Pergamon Press, 242 Marylebone Road, London, NW 1. Subscription (per volume of 4 numbers), £4.10 sh. ($12.60).

This new journal is a reflection of contemporary interest in the floor of the deep sea, which, it is often said, is less known than the face of the Moon. The development of sonic sounding, the invention of the Kullenberg core-sampler, followed by the adaptation of other geophysical devices, have provided us with new techniques for studying an old problem, and accordingly during the last decade a series of new deep-sea expeditions have set forth, many of them to tackle once again problems that were first touched upon by the *Challenger* Expedition (1872–76), but since neglected. These expeditions have been truly international, and world-wide in scope—the *Galathea* (Danish, under Anton Bruun), the *Albatross* (Swedish, under Hans Pettersen, the *Discovery II* (British, under H. F. P. Herdman), the present *Challenger* (British, under G. S. Ritchie), the numerous Atlantic expeditions organized by Woods Hole and by the Lamont Geological Observatory (under Maurice Ewing), the many Pacific expeditions undertaken by the Scripps Institution, La Jolla (under Roger Revelle), often in collaboration with the Navy Electronics Laboratory (San Diego), and others by the French, to the Red Sea, and so on.

At the same time consultative international cooperation has reached a high peak. There is in existence the International Association of Physical Oceanography as one of the constituent bodies of the International Union of Geodesy and Geophysics, and through this organization a Joint Commission on Oceanography was set up in 1948 (and reformed in 1951) under the International Council of Scientific Unions and with the encouragement of U.N.E.S.C.O. This "joint commission" was formed jointly of representatives of the International Union of Geodesy and Geophysics, and of the International Union of Biological Sciences, the present chairman being Dr. J. D. H. Wiseman. The avowed object of the Joint Commission is the study of the deep-sea floor, and the publication of a journal has been included within its terms of reference.

Deep Sea Research is that journal and the scope of the Joint Commission may give a picture of the wide field which it should cover:

1. The morphology and stratigraphy of the deep-sea floor.
2. The general properties of the sediment carpet and its substratum.
3. The properties of the water layer next to the deep-sea floor.
4. The abyssal fauna inhabiting the deep-sea floor.
5. The organisms and processes important to deep-sea sediments.

The first number is of very great interest to all sedimentary petrologists and marine geologists. John Wiseman outlines the history of the famous Monaco bathymetric chart of the oceans and steps being taken now to keep it up to date. He also reviews the widespread developments in deep-sea sedimentational research and the enormous collective value derived from the present happy state of affairs in international collaboration. With a view to continuing it, the Joint Commission is now recommending the formation of a permanent International Deep-Sea Council.

Wiseman also reports on the formation and work of the International Committee on the Nomenclature of Ocean Bottom Features, the existence of which every geologist interested in marine sedimentation or geotectonics should know about. This committee has been active since 1949 and, after wide consultations, has now finally agreed on principles governing nomenclature of bottom features, together with all the more important definitions. The geologist who liked the term "swell" (e.g. Mid-Atlantic Swell) should note that this is now deflated to "rise" or "ridge," following strict rules. Some rather strange-sounding words like "seahigh" must now be added to our dictionary. These names will be incorporated in new editions of the Monaco International Chart.

The other articles in this first number include a review by Hans Pettersen of the progress of the *Albatross* work; a report and discussion by Heezen, Ewing and Miller of a trans-Atlantic traverse with an airborne-type magnetometer, adapted for trailing behind an ordinary steel-hulled vessel; an article by Bernard on the role of calcareous flagellates (coccoliths and so on), which, in depths down to 2000 fathoms, are "the chief subscribers to deep-sea fertility and sedimentation."

Then there is a discussion by Wiseman and Hendey on a unique sample of diatom (*Ethmodiscus*) ooze from 5744 fathoms in the Marianas trench which shows (in electron micrographs) evidence of solution by sea-water; this note is accompanied by some interesting remarks on problems for future investigation in deep-sea trenches. Finally there is a useful review by Gaskell, Swallow and Ritchie of the methods in checking deep-sea soundings together with remarks on the greatest oceanic sounding by the present *Challenger* in the Marianas trench (5899 fathoms for a corrected wire reading; 5940 fathoms for the maximum corrected echo sounding).

This new journal conforms in printing and quality to the high standard set by its stable-mates from the Pergamon Press—Geochimica et Cosmochimica Acta and the Journal of Atmospheric and Terrestrial Physics. Methods of giving an adequate abstract and properly complete references conform to the standards set by the Royal Society and international bodies. We are glad to see adopted the European method of printing authors' names in small capitals; it so facilitates speedy reference to authorities.

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THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

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TURBIDITY CURRENTS AND THE TRANSPORTATION OF COARSE SEDIMENTS TO DEEP WATER, A Symposium, 107 pp. (Nov., 1951) .....Non-Members, $2.75; Members, $2.25 per copy

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